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A SHORT COURSE ON THE THEORY AND OPERATION OF THE FREE BALLOON

By C. H. ROTH, Instructor
THE GOODYEAR TIRE & RUBBER COMPANY
FLYING SCHOOL

SECOND EDITION

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PREFACE

This work is intended to be a brief text on the free balloon, giving the construction and uses of the various parts of the balloon, the preparation for flight and the proper method of handling the balloon while in the air.

The main object in presenting this book has been to embody in collective form, with some attempt at logical sequence, the most important and useful results of practical experience, research work and theory compiled by the recognized authorities on the subject of ballooning. The student as well as the engineer and designer usually experiences some difficulty in endeavoring to extract the information he requires from published records and it is hoped that to these this work will particularly appeal.

In conclusion he wishes to express his appreciation of kindness of R. H. Upson, R. A. D. Preston, Col. C. De F. Chandler, and Dr. Albert Zahm for assistance rendered in the compilation.

C. H. R.

Akron, Ohio, December, 1917.

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Chapter I

Parts of the Free Balloon

The free balloon affords a way in which men may ascend at will to various altitudes and travel great distances by the action of the air currents of the atmosphere.

The lift or ascensional power of a balloon is caused by the fact that the gas which is contained in the gas bag is lighter than the air which it displaces. In the same way a block of wood immersed in water is lighter than the volume of water which it displaces, hence its tendency to rise to the water's surface.

Before we go further into the dynamics of the balloon it is well to know something about the balloon itself, its construction, shape, etc.

THE GAS BAG

Use. To serve as a container for the gas or displacement medium of the balloon.

Shape. The gas bag is usually made spherical as this is the natural shape to equalize fabric strains and also because a sphere has the smallest surface, hence the least weight to contain a given volume. It would be impossible to make a perfect spherical surface from flat surfaces, such as paper. However, this may be closely approximated by considering the sphere made up of a series of frustrums of cones, the small base of one coinciding with the large base of another, etc. (See Fig. 1), and the circumferences of all bases lying on the surface of the sphere. The surface of these cones is developed in the ordinary way and this development cut into small enough pieces to prevent excessive waste in cutting. (Fig. 2). In other words, when the bag is designed the various pieces of fabric are shaped just as if they were paper.

On account of the elasticity of the fabric, when the bag is inflated the fabric becomes a double curved surface and should the bag be weightless and inflated with air it would assume a spherical shape though built as a series of frustrums of cones.

Still another change takes place in its shape when it is inflated with gas and the basket and load suspended below. The sphere now becomes egg-shaped with the small end down. This is because the head of gas in the balloon increases towards the top of the balloon. A good example of this shape can be found by observing a suspended rubber toy balloon filled with water.

The Water Model. The preceding illustration is very useful and much used in determining the shape, factor of safety, stretch, volume, etc., of a balloon before it is built. This is done by making an exact model 1/30 the size of the balloon to be built. All fabric and seams to be same as on full size balloon. This model is suspended by the basket or car in an inverted position and filled with water (Fig. 3), the pressure in the model being measured by a vertical glass tube, the lower end being attached to the balloon and the upper end open, the height of the column of water in the tube determining the pressure in the balloon. The volume or change in volume due to stretch may be measured by the use of a spring balance interposed in the sustaining cord.

The reason for making the water model 1/30 the size of the full sized balloon is given as follows (See Fig. 4): Consider a thin slice cut from both model and balloon at their largest diameter.

Let D = Diam. of full sized balloon (ft.).

" T = Tension in fabric (lbs.).

" Q = Weight of water (lbs. per cu. ft.).

" N = Ratio of diam. of full sized balloon to model.

" P = Lift of gas (lbs. per cu. ft.).

" L = Thickness of strip cut.

Balancing forces on the model and full sized balloon we have the sum of the tension on the fabric on the two sides equal to the volume of the fluid multiplied by its weight per unit volume or

$$2T = \left(\frac{\pi}{4} D^2 L\right) P \quad \text{and} \quad 2T_1 = \left(\frac{\pi}{4} N^2 D^2 L\right) Q$$

Now if we wish to have the same tension in the fabric of both balloon and model, we must equate the values of tension

$$\left(\frac{\pi}{4} D^2 L\right) P = \left(\frac{\pi}{4} N^2 D^2 L\right) Q$$

Cancelling this clears to

$$P = N^2 Q$$

or $N = \sqrt{\frac{P}{Q}}$

The average lift of 1 cu. ft. of hydrogen is approximately .07 lbs. at 70° F. and 30" Baro. pressure while the corresponding weight of water is 62.25, therefore,

$$N = \sqrt{\frac{.07}{62.25}} = \frac{1}{30} \text{ approx.}$$

Thus it can be seen that a 1/30 size model will carry the same strains in its fabric if filled with water and suspended as would be found in the fabric of the full sized balloon filled with gas. Other interesting relations are as follows:

The gross lift of the balloon will be 30 times the weight of the water in the model, for example, if the water in the model weighs 100 lbs., the gas in the full sized balloon would have a lift of 3,000 lbs. exclusive of the weight of the balloon.

The pressure of the water in the model in inches of water will be 30 times that of the full sized balloon, for example if 90 inches of water would burst the model, the full sized bag would rupture at 1/30 of 90 or 3 inches of water pressure.

The total stretch of the fabric on the full sized balloon will be 30 times that of the model.

The volume of the full sized balloon will be 30 x 30 x 30 or 27,000 times the volume of the model.

The stress in the cordage and other concentrated members in straight tension or compression are in proportion to the linear dimension of model and full sized balloon, or as 1 is to 30.

Size. Spherical balloons have been built in all sizes up to 400,000 cu. ft. and even larger. The smaller sizes are used for advertising purposes by suspending a sign from them and anchoring them to the ground. The larger sizes being used for passengers.

Contrary to first thought, it may be stated that there is a limit to the size to which a balloon can be built. Let us consider the following demonstration:

Assume that the pressure in the middle of a balloon of Diam. D is P.

Then $\left(\frac{\pi}{4} D^2\right) P =$ the total force due to pressure tending to rupture the bag.

This force is resisted by the fabric on a great circle of the balloon or a linear length of πD . Hence tension per unit width of fabric due to pressure alone equals $\frac{\pi}{4} D^2 P \div \pi D$ or $\frac{P}{4} D$

The only other stress in the fabric of the balloon is that due to the load. The load is equal to the lift of the balloon which in turn is the product of the volume of the balloon multiplied by the lift per unit volume or $\frac{\pi}{6} D^3 K$ where K=the lift per unit volume. This load is also distributed over the fabric of a great circle hence $\frac{\pi}{6} D^3 K \div \pi D = \frac{K}{6} D^2$ or the tension per unit width due to load. Therefore the total tension in the fabric of a balloon $= \frac{P}{4} D + \frac{K}{6} D^2$

Now if we consider a balloon of N times these linear dimensions, the tension in its fabric will be

$$\frac{P}{4} (ND) + \frac{K}{6} (ND)^2$$

or $N \left(\frac{P}{4}\right) D + N^2 \left(\frac{K}{6}\right) D^2$

Now if we consider the unit weight of the fabric proportional to the tension or strength of the fabric we may express the weight of a unit of surface as $M \left(N \left(\frac{P}{4}\right) D + N^2 \left(\frac{K}{6}\right) D^2\right)$. The total weight of a

a balloon with diam. = ND can be given as its surface multiplied by the weight per unit of surface or

$$4 \pi (ND)^2 \left[M \left(N \left(\frac{P}{4} \right) D + N^2 \left(\frac{K}{6} \right) D^2 \right) \right]$$

$$= (\pi PM) N^3 D^3 + \left(\frac{2 \pi KM}{3} \right) N^4 D^4$$

Now the lift of a balloon of Diam. ND = $\frac{K}{6} \pi N^3 D^3$ hence comparing these last two steps it can be clearly seen that the weight of the fabric increases rapidly with the size of the balloon, as it increases as the fourth power while the lift only as the cube.

Material. The first balloons were made of paper, but naturally on account of their fragility and inflammability (as the first lifting power was hot air created by a fire) this was discarded for something better. However, this was the start and much credit is due the Montgolfier Brothers for their efforts. Shortly after this time hydrogen was used as a lifting power but on account of its lightness it was very difficult to build a light bag which did not leak. At last a substance known as gold beaters' skin was found and a balloon was built of it which was very satisfactory except for the cost. Gold beaters' skin is a thin membrane taken from the internal organs of the ox, one animal giving one piece about 6 inches square. However, considering the high cost of this material it is excellent and served its purpose well as it was almost perfectly gas tight and very light.

On account of the high cost and scarcity of this material it became necessary to look further for satisfactory balloon material. The next step was the varnished fabric. Both cotton and silk were varnished and used as balloon fabric with fair results. The product was much cheaper, fairly light as it was made of but a single ply of fabric but not nearly as impervious to hydrogen as gold beaters' skin, furthermore it became more porous every time it was folded as the varnish would crack causing the added expense of frequent re-varnishing. Another fault with this type of fabric was the fact that when it was wrapped up and stored away it was liable to catch fire due to spontaneous combustion, and on the whole it was only used in the absence of something better. At last the something better appeared and is almost universally used today. It is the rubberized balloon fabric.

Rubberized Balloon Fabric is made in various weights, colors and number of plies; however, the two ply fabric is most used for ordinary purposes, though a three ply fabric is often used on the larger gas bags where great strength is required.

The following is a brief description of the process of the manufacture of balloon fabric at the Goodyear Tire & Rubber Company, Akron, Ohio.

The raw fabric is first passed over a glass table which is illuminated from below with electric lights. Here all defects are removed. A sample from each roll is tested for strength and the number of threads per inch counted to make sure the fabric is up to the standard.

The fabric is now run through the spreader (See Fig. 5) time after time until the required weight of rubber has been spread on the fabric. Sometimes it is necessary to "spread" the fabric 30 times before the required weight of rubber has been applied to a square yard. The compound spread on the fabric is a secret mixture made of the purest grades of material accurately and carefully mixed and closely resembling a thin putty. Two rolls of this fabric is spread in the manner described. The one is left as it is while the other is cut into bias pieces 45° to the edge of the fabric. These bias pieces are all turned around and cemented together again to form a continuous roll of bias fabric. These two rolls are now run through another machine which rolls the two plies together into the 2 ply fabric. These two plies are held very firmly together by the action of the adhesive properties of the rubber. It may be said that rubber before it is "cured" or heat treated is very sticky. The electricians friction tape is a good example of this property of uncured rubber.

The question may be asked as to the use of the bias ply. Its purpose is to oppose the diagonal stretch of the straight ply and to make the fabric equally strong in every direction and to prevent tears from spreading.

During all of these steps of spreading it is necessary to wrap a clean piece of fabric with the spread fabric in order to keep the layers of spread fabric from sticking together. After the fabric has been plied up, it is wrapped on a large iron drum with a clean strip of fabric as before and the edges of the roll are tightly bound to prevent moisture from passing into the roll between the layers of fabric.

This drum with fabric is now lowered into a "heater" and the heater bolted shut. Steam is admitted into the heater, which cures the fabric removing all signs of stickiness. The correct temperature and pressure of steam in the heater and the length of cure are very important factors in the production of balloon fabric. Should the cure be too great, the rubber becomes too hard and cracks, if too little the diffusion is bad and the fabric is sticky. The best of skilled labor is required in the manufacture of balloon fabric.

After the fabric is completed every roll is again passed over the glass table to detect flaws. A strip is tested for strength and a disk tested for diffusion.

By **diffusion** (with reference to ballooning) is meant the volume of gas which passes through a unit area of balloon fabric in a given time under standard conditions. These requirements vary greatly with the purpose for which the fabric is to be used, for example, a free balloon does not need to be nearly as gas tight as a dirigible.

Diffusion is usually given as the number of cu. ft. of hydrogen which will pass through a square meter of fabric in 24 hours at 25° C temperature 760 mm Baro. pressure with gas pressure of 30 mm of water. The diffusion of fabric used for dirigibles and kite balloon construction is usually from .3 to .4 cu. ft.

The method of obtaining this diffusion at the Goodyear Tire & Rubber Company which is the method required by the Government for this purpose is briefly described as follows:

A constant pressure of hydrogen is maintained on one side of a test piece of fabric while air is passed by the other side taking with it the hydrogen which had diffused through the fabric, which hydrogen is burned to water in a combustion furnace and weighed, giving with a simple calculation the leakage of the fabric over a definite time interval. With this apparatus the only joint under appreciable pressure which must be kept tight is that between the fabric and the bottom half of the drum.

The technique of the test is as follows: The two hemispheres of the bronze diffusion drum (6) (Fig. 6) are opened and the balloon fabric diaphragm (7) to be tested is inserted, the two halves of the drum being then bolted together so securely that the joint is gas tight. The drum is then placed in a thermostatic bath (not shown in diagram) and brought to the required temperature, usually 20 deg. C.

When the drum and its contents have attained the desired temperature, hydrogen is allowed to pass from the cylinder (1) through the gas washing bottle (2) filled with strong sulphuric acid for drying the hydrogen, thence through the preheating furnace (3) whose purpose is to burn all organic gaseous impurities in the hydrogen and to combine any contained oxygen with it to water; the purified gas then passes through the gas washing bottle (4) filled with caustic potash solution to remove traces of carbon dioxide, etc., and then through the bottle (5) filled with strong sulphuric acid to remove the last traces of water; thence into the under side of the diffusion drum (6).

The purified hydrogen gas is passed into the lower half of the drum (6) and out through the tube (15) until all the residual air contained in this lower half has been swept out and replaced by hydrogen. The tube (15) is then closed and the pure hydrogen allowed to diffuse upward through the diaphragm for a definite time.

The hydrogen diffusion through (7) into the upper half of the drum (6) is swept out by a current of air admitted through the tube (14). The hydrogen containing air passes thru the gas washing bottles (9 and 10) whose purpose it is to remove any adventitious moisture, they being filled with strong sulphuric acid; thence, the gases pass into a heated combustion tube (11) filled with platinized asbestos, where the hydrogen is burned to water, which in turn is absorbed and weighed in the Geissler bulb (12 and 13).

No. 8 is a pressure regulating device whose function is to maintain a constant gas pressure in the lower half of the diffusion drums, the pressure usually equaling a 2-inch column of water.

Knowing the exposed area of diaphragm, the time of diffusion, and the weight of the water obtained by the combustion of the diffused hydrogen, a simple calculation enables us to determine the diffusion per square yard in 24 hours, and results are always reported as cubic feet of hydrogen diffused per square meter in 24 hours at the given standard temperature and pressure.

The reason for making the fabric as gas tight as possible is twofold, first, to prevent the passage of gas into the air, second, the passage of air into the gas. The latter is by far the most important especially in dirigibles as it is a very simple matter to replace gas when it is lost, but a very difficult matter to remove the air that has mixed with the gas. The action of this air is the same as so much ballast. Every cu. ft. of air that finds its way into the balloon displaces just that much hydrogen, hence, acts the same as any other ballast.

This intermixing of gases takes place when two gases are separated by a membrane independent of the density of the gases involved. An excellent example can be given by the following laboratory experiment:

Fill a glass beaker with oxygen and cover with a glass plate. Fill a second beaker with hydrogen and place over the beaker containing the oxygen. Replace the glass separating plate with a piece of balloon fabric. After half an hour test each beaker with a lighted taper and an explosion is the result in either case showing that the lighter hydrogen has passed down thru the fabric and mixed with the heavier gas while the oxygen has passed up into the lighter hydrogen. This is identical with the action that takes place in a balloon.

The various **Properties** of the fabric depend as was before stated on the purpose for which the fabric is intended. The number of plies of cloth, its raw weight, the weight and color of the compound are all varied to suit requirements.

Take for example a fabric manufactured by the Goodyear Tire & Rubber Company which is used in the manufacture of free balloons and portions of kite balloons and dirigibles which are not subjected to excessive tension. This is a 2 ply bias (one ply laid on the bias) fabric having a total weight of about 8 oz. per square yard total, including the 2 plies of cloth each of which weighs about $2\frac{1}{2}$ oz. per sq. yd. This fabric has a tensile strength of 50 lbs. per inch width of fabric in its four principal directions.

A heavier fabric is also manufactured for use in dirigibles and kite balloons. This is similar to the 8 oz. fabric except that the straight ply of fabric is made of a heavier grade of material having a weight of about $4\frac{1}{2}$ oz. per sq. yd. making a total of a little over 10 oz. per sq. yd. This fabric has a tensile strength of about 80 lbs. per inch of width with the warp (parallel to the edge) and 50 lbs. with the web (across the roll).

Still stronger fabrics can be made, but whenever the strength is increased the weight or load to be carried by the gas also increases. For this reason fabric heavier than the latter one given is seldom used except on balloons and dirigibles of very large diameter. A stronger fabric could be made in several ways, by increasing the number of plies of fabric, increasing the strength, hence, weight of the raw fabric, or by adding reinforcing cords between the plies. Each one of these methods would greatly increase the weight of a gas bag. For example, a dirigible gas bag built of 10 oz. fabric and weighing 1500 lbs. would weigh about 400 lbs. more if built of fabric weighing but $2\frac{1}{2}$ oz. more per square yard. This additional weight would require an additional volume of almost 6000 cu. ft. to support it, then in turn this additional volume requires a larger, hence, a still heavier bag to contain it so it can be seen that the lighter the fabric used the smaller can be the gas bag for a given lift.

The gas tightness of a fabric depends upon the rubber between the plies. The necessary quantity of rubber required for this purpose is about 3 oz. per sq. yd. Little or no rubber is put on the inside of the balloon fabric and very little on the outside just enough to give it a color and protect it from moisture. Some advocate the entire absence of rubber except between the plies stating that it can serve its purpose there improving the diffusion while the fabric is dyed to give it color and treated with a moisture resisting compound.

Seams are made in the following manner. First, the fabric is washed perfectly clean with benzine, gasoline will do in emergency, and allowed to dry. Then both surfaces are given 3 coats of thin balloon cement, C-35 will do if standard balloon cement is not available. Each coat of cement is allowed to dry at least 15 minutes, depending on the weather, at the same time, it is shielded from the sunlight and protected from the dust. The two surfaces are now laid together on a flat surface and thoroughly rolled. Should it be necessary for any reason to separate the plies after they have once been laid together, benzine should be used to soften the cement and in every case both surfaces should again be cemented as previously described before they are laid together again. The standard width of seam on sphericals and small gas bags is $\frac{3}{4}$ " while 1" is the standard seam width on larger gas bags.

This cemented seam is now run thru a sewing machine which sews the seam with two rows of stitches $\frac{3}{8}$ " apart. In order to prevent leakage through the perforations caused by the needles and also to hold down the edge of the fabric a light bias strip of uncured coated fabric $1\frac{1}{2}$ " wide is securely cemented and rolled over the stitches and edge of fabric on both sides of the seam (no cement being required on the tape).

As far as the strength of the seam is concerned it is 100% efficient (i. e., as strong as the fabric) even without sewing. Many tests of seams have been made and to my knowledge a seam has never been known to fail. However, the stitches are usually added as an additional safety factor, as their weight is practically nothing.

Care of Balloon Fabric. Oil is very harmful to balloon fabric and should be immediately removed with gasoline.

EXTREME TEMPERATURES are detrimental to fabric, sometimes causing it to crack and lose its gas tightness.

MOISTURE wrapped up with a balloon causes mildew and mold and should be avoided. If necessary to wrap up fabric while wet, it should be unrolled again as soon as possible and allowed to dry.

SUNLIGHT is as detrimental as heat and causes rapid deterioration of fabric. A short time ago a gas container was sold to a concern which installed the same in a room in such a way that the one side was kept fairly dark while the other side was exposed to the action of the sun for certain hours of the day. It was indeed surprising to note the change in the characteristics of the fabric of this container within a few months' time. The side which was kept dark was apparently as strong as ever while the side exposed to the sun only part of the day had deteriorated to such an extent that it could easily be punctured by the pressure of a man's finger.

SCRATCHES OR HOLES naturally effect the diffusion and should be avoided. One of the great causes for decrease in gas tightness of a gas bag is the method of handling the bag before and after inflation. The fabric should never be dragged over sharp objects and most important of all, no one should be allowed to walk on the balloon unless in their stocking feet or wearing shoes which have absolutely no nails in them, such as tennis shoes, etc.

PATCHING HOLES. The patch should be cut so as to have a lap of two inches on all sides of hole or slit. The edge of this patch should be made jagged or star shaped. Both the patch and the fabric about the hole should be washed with benzine and after drying, given two or three coats of cement in the same manner as seams are made allowing each to become thoroughly dry. The patch is now applied and thoroughly rolled in place. The jagged edge of the patch is to keep the patch from peeling off if it gets loose at the edge.

THE NET

Use. The net is a network of cords which is thrown over the gas bag and attached to the load below in such a way that the load is distributed over the entire balloon.

The net also takes practically all the strain off the fabric. The only strain in the fabric is that due to the head of gas and as the appendix is open practically all of the time this is very small. In a dirigible, however, the load is usually attached directly to the fabric so that the tension in the fabric is due to the sum of both the pressure strain caused by quite a large head and the load in the car. Thus it can be seen that very light, weak material could be used for a free balloon. Also as the gas is never kept in a free balloon for any great length of time, the fabric does not need to have such a low diffusion as for dirigibles in which the gas is kept for weeks and sometimes months. Considering this it can be seen why paper and varnished cotton and silk were satisfactory in their day for balloons used for free ballooning. Today, however, the rubberized fabric is practically the only material used for good gas bags.

Material. Nets are made from cotton, Italian hemp, silk and linen cords. A net is very light anyway; hence, considering the high price of material there is little advantage in using silk. Linen soon deteriorates especially when wet, and also has a tendency to cut the knots of the net. There has been considerable discussion as to the superiority of cotton or hemp for balloon nets. Cotton certainly is some heavier, but it is more dependable, in other words more reliable. Best authorities seem to favor the cotton in preference to the Italian hemp in spite of the slightly greater weight on account of the greater reliability, probable longer life and less tendency to cut at knots.

Construction. The net is made of diamond shaped meshes, each ring made up of diamonds of the same size. The number of meshes around the balloon is the same for each ring and is made a multiple of 8 and sometimes 16 depending upon the size of the balloon in order that each "foot" rope may accommodate the same number of meshes. The size of the diamonds in each ring decreases towards the top of the balloon, the number of diamonds in each ring remaining the same. The diamonds are usually made with their diagonals in the ratio of 2 to 1. The long diameter on a meridian of the sphere.

At the top or center of the net is a rope ring slightly larger than the valve that is used in the top of the balloon, the upper ring of meshes are attached to this ring. The easiest way to make a net would naturally be to start at the rope ring at the top and tie in a ring of meshes, then to tie a second ring of meshes to the first ring, and a third ring to the second, etc., enlarging the size of meshes with each ring. Unfortunately, however, this is not the best way, for the knots slip when a sand bag is hung on the net. This objection can be overcome by starting with the largest ring of meshes and finishing with the rope ring, in this way, the knot is inverted and hence will not slip (See Fig. 7).

The size of the cords used in making a net are gradually decreased towards the center.

The "foot" ropes are the ropes which are attached to the load ring, or the largest ropes on the net. These ropes terminate in an eye splice which furnish a quick method of attachment to the load ring. There are a number of ways in which the foot ropes may be attached to the meshes of the net (Fig. 8), shows one of the most common methods. The strength of each of the ropes of the crowfoot (ropes branching from the foot ropes to the meshes of the net) as well as all the cords in the net are carefully calculated so that the entire net may be light and uniformly strong throughout, in other words figuratively speaking so that all links of the chain shall have the same strength for it would do no good to strengthen one link more than the weakest link. The meshes of a net are usually brought about $\frac{2}{3}$ the radius of the balloon below the equator before attaching the crowfoot. The crowfoot is made of such dimensions that when the balloon is full of gas and the sand bags concentrated in the lowest loop of the crowfoot, the balloon shall be high enough to attach the basket in place underneath. The foot ropes are usually made about equal to the radius of the balloon or a little longer.

No net is used on small balloons, in order to save weight. The crowfoot in this case being attached to suspension patches cemented to the balloon. Here the entire strain is carried by the fabric itself, but as the balloon is small the factor of safety is large enough.

THE BASKET

Use. Naturally as the name implies the basket is a container and carries all the load and passengers.

Material. Balloon baskets are usually made of reed or willow. Willow baskets are brittle and soft and lose their shape easily. Reed baskets, even though they are some heavier than those made from willow, are much more durable and reliable, hold their shape better than the willow, and still have just enough flexibility to keep them from going to pieces on landing.

Construction. Balloon baskets are woven like any other kind of basket except that under the floor of the basket are 4 or 5 tough wooden skids while a wooden floor is laid inside. The rim of the basket is made extra strong to take the strain of the suspension ropes. There are usually 8 suspension ropes, or in reality only 4 ropes with 8 ends. These ropes are woven into the basket during course of construction, they pass down one side under the bottom and up the other side making four supporting ropes under the basket. About five feet of rope is left above the rim of the basket and the end of each rope terminates in an eye splice.

Dimensions. Balloon baskets are usually $3\frac{1}{2}$ feet high and if designed to carry two men and ten or twelve bags of ballast should be about 3 feet wide and $3\frac{1}{2}$ feet long. This basket will carry three persons, though it will be quite crowded. A basket of this description and built of reeds will weigh about 60 lbs.

Four wooden handles are attached by ropes to both the inside and the outside of the basket. Those on the outside are for the purpose of carrying the basket, while those on the inside are to hold to when the basket is being roughly dragged over the ground.

THE LOAD RING

Use. The load ring furnishes a convenient method of attaching the foot ropes to the basket. It also furnishes a semi-concentrating point which prevents the basket from swaying at the same time that it equalizes the strains on the net.

Material and Construction. The load ring is a wooden ring from 2 to 3 feet in diameter and 2 to 3 inches wide and about half that thick depending on the size of the balloon. It is usually made of several laminations of oak glued together. Eight pairs of oak or brass pegs are equally spaced around the top edge of this ring in order to keep the ropes for the eight basket rope toggles spaced equally around the ring. In a similar way pegs are spaced equally about the bottom edge for the foot ropes, having just as many pairs of pegs as there are foot ropes. Wooden toggles are spliced as close to the wood ring as possible. The eyes in the ends of the basket ropes and foot ropes are simply slipped over these toggles making a secure connection between balloon and basket. Another toggle is attached to opposite sides of the wooden ring by a rope in such a way that it hangs down 2 or 3 feet below the ring. This is for the attachment of the drag-rope.

THE GAS VALVE

The use of the valve is to discharge gas from the balloon. It is located at the extreme top of the balloon as the head of gas is greatest there, hence, it is the most effective location for the valve. Also because

the valve cord runs directly from that point to the basket. The kind of valve usually used in free balloons is of the butterfly type. This type is used because it will stand the hard usage which it is likely to get without leaking badly. The valve is made of two oak rings between which the fabric of the balloon is clamped by bolts and wing nuts. On a wooden diameter of the inner one of these rings is hinged two semi-circular panels or doors which furnish the outlet for the gas. These doors are held shut by rubber springs which are attached to the upper end of a central post and are pulled open against the tension of these springs by ropes on the inside of the balloon which lead to the basket. Felt gaskets are glued to both door and ring to prevent leakage of gas. A cone shaped cover is attached over the valve to keep rain out of the balloon. There is space, however, between the lower edge of the cover and the balloon to allow all the gas to escape which comes out of the valve.

THE APPENDIX

The appendix is located diametrically opposite the gas valve at the lowest point on the gas bag. It is really nothing more than a vertical sleeve attached to the balloon but it serves three purposes. First, it affords an inlet for the gas during the inflation, second, it forms a convenient and well located opening for bringing the valve cord out of the balloon, and third, it acts as a safety valve. When a balloon rises to a higher altitude or increases in temperature it increases in volume as will be shown later, and should this additional volume not be liberated the bag would be liable to burst. The appendix is left open practically all the time during flight; hence, any change of pressure due to increase in volume will automatically be relieved.

The appendix is made of fabric, its length and diameter depending upon the volume of the balloon. The proper dimensions for a 19,000 cu. ft. spherical balloon are length $5\frac{1}{2}$ ft. and diam. 9 inches to take care of the expansion of $\frac{1}{30}$ of its volume per minute which is approximately equivalent to a vertical velocity of 1000 ft. per minute. The corresponding size of the gas valve considering the increase in head of gas at the top of the balloon should be approximately 8 inches. Both gas valve and appendix are made larger than these figures to be on the safe side and allow a certain factor of safety.

The bottom of the appendix is reinforced with a cord to reduce the danger of splitting the fabric sleeve. The appendix bridle is composed of four light ropes attached to the bottom of the appendix at points equally spaced around it. These four ropes are spliced together into a single cord which is carried to the basket and will hereafter be referred to as the bridle cord. The use of the bridle cord as will be explained in detail later is to keep the balloon from parachuting on landing. This is done by tying the bridle cord securely to the basket before deflating while in the air. If this were not done the gas would leave at the top of the balloon and the fabric in the bottom of the gas bag would be forced upward forming a parachute or pocket for the wind which would be liable to drag the basket a considerable distance with possible disastrous results.

Some authorities advocate the use of a removable appendix and that the bridle cord should be attached to the rings at the base of the balloon which are used in removing the appendix. This may have been good practice with paper or varnished fabric balloons as the balloon material was not strong enough to stand the strain of the bridle cord, but now that balloons are made of a much stronger material the old practice has been to a great extent abandoned. Also there is little or no reason for ever removing the appendix from a balloon.

THE RIP CORD GLAND

The rip cord gland is nothing more than a sleeve or appendix about 2" in diameter and about 2'-0" long. It serves the same purpose for the rip cord that the appendix does for the valve cord, it furnishes an outlet for the rip cord. A separate outlet is made for the rip cord so as to leave no possible chance of the two control cords to become twisted.

The rip cord gland is located directly below the upper end of the rip cord about 2'-0" from the appendix.

To prevent leakage of gas during flight this sleeve is tied shut with breakable string in such a way that when the rip cord is pulled this light string is broken first opening the sleeve and allowing the rip cord to be pulled freely.

Another system that is used by some manufacturers is to pass the rip cord thru a hole in a cork so that it will fit tightly. The rip cord passes thru a small metallic ring at the base of the balloon and the cork is forced snugly into the opening of the ring, thus preventing any leakage of gas. When the rip cord is pulled the cork is first removed from the metallic ring leaving the rip cord free.

THE RIP PANEL

The rip panel is for rapid deflation when landing. It is merely a reinforced slit in the balloon over which a reinforced strip of fabric is cemented. In the upper end of this reinforced strip or "panel" is attached a short stout stick to which the rip cord is tied. A patch is located near the end of the rip panel to which the rip cord is attached with breakable string in order to keep the strain due to the weight of the rope off of the rip panel. About 6 ft. of slack rope is left between the panel and the patch as a precaution in case the rip cord should accidentally be pulled. When the rip cord is pulled the breakable string around the rip cord gland is first broken, then the string near the end of the rip panel is broken, then if the cord is pulled still farther the panel is pulled into the balloon leaving a long slit near the top of the balloon permitting the gas to escape rapidly. The rip panel is usually made equal to $\frac{1}{4}$ or $\frac{1}{5}$ the circumference of the balloon in length and is located on a meridian of the sphere with the upper end about 3'-0" from the gas valve. All seams of the balloon as before described are $\frac{3}{4}$ " in width and double sewed and double taped. The rip panel is simply cemented in place with a $1\frac{1}{2}$ " lap and then taped. To sew the panel in place would make it too difficult to remove, besides even a $\frac{3}{4}$ " unsewed seam is 100% as strong as the fabric. Whenever a rip panel is to be replaced after a flight it is necessary to remove all traces of the previous rubber cement. This is done with a piece of soft rubber similar to the manner in which a pencil line is removed from a sheet of paper with an eraser.

In order to distinguish between the rip and the valve cord the valve cord is made of white rope and the rip cord from a point a little above the load ring to the basket is made of tape of $1\frac{1}{2}$ " wide. In this way when it is dark there is no danger of ripping the balloon when it is desired to valve.

THE DRAG ROPE

The drag rope is a long heavy rope which is carried along in the basket to let hang out and drag on the ground in order to lighten the basket when occasion demands. It may be termed "recoverable" ballast as it is weight which can be thrown out of the basket onto the ground and pulled back again. It is often used when passing under a cloud in order to save ballast or at night when it is desired to ride low and also when landing from a high altitude in order to gradually lighten the balloon as it descends towards the earth.

When drag roping over wires the rope has a tendency to snap and twist around the wires tearing them off and jerking the balloon about very roughly. This action is removed to a great extent by tapering the end of the rope for 15 or 20 ft. and tightly lashing it all the way with stout cord. This makes a stiff end which will not twist about wires or easily catch in trees. The proper length of the drag rope can be taken as $5D + 60$ ft. where D is the diameter of the balloon in feet. A drag rope of this length and of

weight, w, will stop a FORCE OF DESCENT of $\frac{3.5 Dw}{5D + 60}$ lbs. without hitting 60 ft. trees.

The proper weight for the drag rope should be calculated from the preceding empirical formula considering that the drag rope should be sufficient to stop a force of descent equivalent to a contraction of about 2% of the volume of the balloon.

Example—Required weight of drag rope (w) for a 19,000 cu. ft. balloon 33 ft. in diameter filled with hydrogen:

$$19,000 \times .07 \times 2\% = \frac{3.5 \times 33 w}{(5 \times 33) + 60} \text{ or } w = 52 \text{ lbs. approximately.}$$

The drag rope is coiled up similar to a ball of twine, the rope running diagonally across the coil. The tapered end always on the outside. After the rope has been coiled up a $\frac{1}{4}$ " rope is bound tightly around it and it is slipped off the tapered reel and tied to the outside of the basket with another rope in such a way that by cutting a single rope the entire coil of rope is released. The inside end of the coil of course having been previously attached to its toggle on the load ring. A considerable shock would naturally be expected when this heavy coil of rope is suddenly dropped but this is not the case, the weight of the coil is transferred gradually to the load ring as the rope uncoils so that no part of the weight comes suddenly on the balloon. Should the rope be coiled in any other manner there is always more or less jerking and jarring when the coil is dropped as the coil tends to rotate and roll over. With the proper method of coiling, the rope is fed from the center so that there is no chance to rotate or roll and there is no jar whatsoever.

MISCELLANEOUS

At the Goodyear they find it pays to make all important material of the highest grade obtainable. Every roll of fabric that comes into the receiving room is carefully tested for strength, the number of threads per inch counted and the entire roll inspected for flaws.

Most all ropes are of the grade called "yacht rope" which is the best rope obtainable, the rope having an especially strong and long fibre often attaining a length of 16 feet. The rope is also tested in a tensile machine to be sure that it is up to the standard.

Every roll of finished fabric is tested for diffusion and inspected for flaws.

Every splice and seam is made 100% strong or in other words as strong as the fabric or rope itself.

It is endeavored to maintain a factor of safety of eight throughout the entire balloon which is the same factor of safety that is used on our largest bridges.

Chapter II

Physical Properties of Gases and the Atmosphere

Gases are bodies which unlike solids have no independent shape and unlike liquids have no independent volume. Gases and liquids have several properties in common, and some in which they seem to differ are in reality only different degrees of the same property. Thus, in both, the particles are capable of moving; in gases with almost perfect freedom; in liquids not quite so freely, owing to a greater degree of viscosity. Both are compressible, though in very different degrees. If a liquid and a gas both exist under the pressure of one atmosphere, and then the pressure is doubled, the liquid is compressed by about the $\frac{1}{20,000}$ part of its volume, while the gas is compressed by one-half. In density there is a great difference: water, which is the type of liquids, is about 770 times as heavy as air, the type of gaseous bodies, while under the pressure of one atmosphere. A gas has no original volume; it is always elastic, or, in other words, it is always striving to attain a greater volume; this tendency to indefinite expansion is the chief property by which gases are distinguished from liquids.

By the aid of pressure and low temperatures, the force of cohesion may be so far increased in many gases that they are already converted into liquids, and with sufficient pressure and decrease of temperature all gases may be liquified. On the other hand, heat, which increases the kinetic energy of the molecules, converts liquids, such as alcohol, ether, and water, into the aeriform state in which they obey all the laws of gases. An aeriform substance is called a vapour or a gas according as it can or cannot without change of temperature be compressed into a liquid; that is, it is a gas if its temperature is above its critical temperature and a vapour if below. Formerly, it was usual to describe as a vapor a substance which at ordinary temperatures is liquid (for instance steam), and as a gas a substance which, at ordinary temperatures and pressures, exists in the gaseous state.

In describing the properties of gases we shall, for obvious reasons, refer to atmospheric air as their type.

Expansibility of Gases. This property of gases, their tendency to assume continually a greater volume, is exhibited by means of the following experiment: A bladder, closed by a stopcock and about half full of air, is placed under the receiver of the air-pump. When the pump is worked the bladder immediately distends. Under ordinary conditions, the pressure inside the bladder is counterbalanced by that of the air in the receiver, which is equal and opposite. But when the pressure outside the bladder is removed or partially removed, by exhausting the receiver, the internal pressure becomes evident. When air is admitted into the receiver, the air in the bladder resumes its original volume. This is identical with the action that takes place in a partially filled balloon as it rises into atmosphere of lesser density.

Atmospheric Pressure. The pressure of the air on the earth's surface is due to the weight of the air above it, for example the pressure of the atmosphere on a square inch of the earth's surface is equal to the weight of a column of air of one inch cross section and extending as high as the atmosphere, normally 14.7 pounds at the sea level. Due to the greater weight of air nearer the earth's surface the gas is denser, therefore it is clear that the weight of the column of air, hence the atmospheric pressure, decreases with increasing altitudes. This decrease is not uniform as the composition of the air changes at various altitudes. For convenience the normal sea level atmospheric pressure is taken at 15 pounds per square inch, called the pressure of one atmosphere, which is equivalent to the weight of 30 cubic inches of mercury. The normal sea level pressure would be represented by a column of mercury in a vacuum 30 inches in height. If a gas is compressed in a gas bottle to a pressure of 10 atmospheres it exerts a pressure of 10×15 or 150 pounds per square inch on the surface of the container. The barometer, the instrument of atmospheric pressure measurement, will be described in a later chapter.

Absorption of Gases—By Liquids. Water and many liquids possess the property of absorbing and dissolving gases. Under the same conditions of pressure and temperature a liquid does not absorb equal

volumes of different gases. At 0°C and 760 mm. pressure one volume of water dissolves the following volumes of gas:

Hydrogen.....	.019
Nitrogen.....	.02
Oxygen.....	.04
Carbon Dioxide.....	1.79
Ammonia.....	1046.63

Gases are more soluble in some liquids than others, for example at 0°C alcohol dissolves 4.33 times its own volume of Carbon Dioxide.

The whole subject of gas absorption may be summed up in the following rules:

1. For the same gas, the same liquid and the same temperature the weight of gas absorbed is proportional to the pressure. This may also be expressed by saying that at all pressures the volume dissolved is the same; or that the density of the gas absorbed is in constant relation with that of the external gas which is not absorbed.

Accordingly, when the pressure diminishes, the quantity of dissolved gas decreases. If a solution of gas is placed under the receiver of an air-pump and the pressure is diminished, the gas obeys its expansive force, and escapes with effervescence.

2. The quantity of gas absorbed decreases with the increase of temperature; that is to say, when the elastic force of the gas is greater. Thus at 15° water absorbs only 1.00 volume of carbon dioxide.

3. The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of other gases which it may already hold in solution.

This absorption of gases may be determined by the absorbtometer, a description of which can be found in Ganot's Physics or any other standard Physics text.

Diffusion of Gases. When two different gases are separated by a porous diaphragm, an interchange takes place between them, and ultimately the composition of the gas on both sides of the diaphragm is the same; but the rapidity with which different gases diffuse into each other in these circumstances varies considerably. The nature of the material of the porous diaphragm has no influence on the rate of diffusion; the phenomena depends upon molecular action and the rate of interchange depends only on the mass of the molecules, i. e., on the specific gravities of the gases. The laws of the diffusion of gases were investigated by Graham. Numerous experiments illustrate them, some of the most interesting of which are the following:

A glass cylinder closed at one end is filled with carbon dioxide gas, its open end tied over with a bladder, and the whole placed under a jar of hydrogen. Diffusion takes place between them through the porous diaphragm, and after the lapse of a certain time hydrogen has passed through the bladder into the cylindrical vessel in much greater quantity than the carbon dioxide which has passed out, so that the bladder becomes very much distended outwards. If the cylinder is filled with hydrogen and the bell-jar with carbon dioxide, the reverse phenomenon will be produced—the bladder will be pressed inwards. (Figs. 12 and 13.)

A tube about 12 inches long, closed at one end by a plug of dry plaster of Paris, is filled with dry hydrogen, and its open end then immersed in a mercury bath (Fig. 14.) Diffusion of the hydrogen towards the air takes place so rapidly that a partial vacuum is produced, and mercury rises in the tube to a height of several inches. If several such tubes are filled with different gases and allowed to diffuse into the air in a similar manner, in the same time, different quantities of the various gases will diffuse, and Graham found that the law regulating these diffusions is that, the quantity of a gas which passes through a porous diaphragm in a given time is inversely as the square root of the density of the gas. Thus, if two vessels of equal capacity, containing oxygen and hydrogen, are separated by a porous plug, diffusion takes place, and after the lapse of some time, for every one part of oxygen which has passed into the hydrogen, four parts of hydrogen have passed into the oxygen. Now, the density of hydrogen being 1, that of oxygen is 16; hence the rapidity of diffusion is inversely as the square roots of these numbers. It is four times as great in the one which has 1/16 the density of the other.

Let the stem of an ordinary tobacco pipe be cemented, so that its ends project, in an outer glass tube, which can be connected with an air-pump and thus exhausted. On allowing then a slow current of air to enter one end of the pipe, the nitrogen diffuses more rapidly on its way through the porous pipe than the

heavier oxygen, so that the gas which emerges at the other end of the porous pipe, and which can be collected, is richer in oxygen, and by repeating the operation on the gas which has passed through, the proportion of oxygen is so much increased that the gas can relight a semi-extinguished taper. To this process, in which one gas can be separated from another by diffusion, the term "atomolysis" is given.

A porous pot, A, Fig. 15, such as is used in voltaic cells, is fixed by means of a cork to the glass tube, which contains water up to the bulb, C, the upper part containing air. When a beaker containing hydrogen, B, is placed over the pot, the diffusion of the hydrogen into it is so rapid that the water is at once driven down and jets out. When the beaker is removed, the gas inside the pot, being richer in hydrogen, now diffuses out with great rapidity, and the water rises in the tube much higher than its original level.

Mixture of Gases. If a communication is opened between two closed vessels containing gases, the gases at once begin to mix, whatever be their density, and in a longer or shorter time the mixture is complete, and will continue so unless chemical action is set up, each gas filling the whole available volume. The laws which govern a mixture of a number of gases may be thus stated:

1. The mixture takes place rapidly and is homogeneous; that is, each portion of the mixture contains the gases in the same proportion.
2. The pressure of the mixture is equal to the sum of the pressures of the component gases, if they occupy the same space alone.

If P_1 , P_2 , etc., are the pressures which the several gases would exert if they alone filled the space V and P is the pressure of the mixture, then

$$P = P_1 + P_2 + P_3 + \text{etc.}$$

This is known as Dalton's law of partial pressures.

Suppose a number of gases, all at the same temperature, having volumes v_1 , v_2 , etc., and the pressures p_1 , p_2 , etc., are transferred to a receiver whose volume is V . If P_1 , P_2 , etc., are the pressures which these gases severally exert we have by Boyle's law $p_1 v_1 = P_1 V$, $p_2 v_2 = P_2 V$, and so on.

Therefore $p_1 v_1 + p_2 v_2 + \text{etc.} = pv = (P_1 + P_2 + \text{etc.}) V = PV$, P being the pressure of the mixture.

Density of a gas is its weight per unit volume. In the English system this is taken as the weight of a cu. ft. in pounds while in the metric system it is the weight of a cubic meter in kilograms. The density of a gas increases with increase in pressure, because the same weight of gas has been compressed into a smaller volume. In the same way the density increases with decrease in temperature because when a substance decreases in temperature it contracts and the same weight has a less volume, hence, greater density. Several methods of obtaining density of a gas are described in Ganot's Physics.

Specific Gravity or relative density of a gas is the ratio of the weight of a unit volume of the gas to the weight of an equal unit volume of air both measured at the same temperature and pressure, or briefly, the ratio of the gas density to the air density both at same temperature and pressure. Specific gravity is independent of pressure or temperature if the gas be a perfect gas. There are no theoretically perfect gases, but air and the gases used in ballooning so nearly approach perfect gas, especially at the temperatures and pressures at which ballooning is carried on, that the above definition may be used with great accuracy.

$$S = \frac{d \text{ (gas at any temperature)}}{d \text{ (air at same temperature as gas)}} = \text{a constant where } S \text{ is specific gravity and } d \text{ is the density.}$$

Specific Gravity or RELATIVE density of gases at 0°C and 76. cm pressure, that of air being taken as unity.

Air.....	1.0000
Hydrogen (pure).....	.0693
Ammonia.....	.5367
Marsh Gas.....	.5590
Carbon monoxide.....	.9670
Carbon dioxide.....	1.5290
Nitrogen.....	.9714
Oxygen.....	1.1057

Boyle's Law (Pressure). When the temperature of a gas is kept constant the density of the gas is directly proportional to the pressure and the volume is inversely proportional to the pressure.

$$d_1 : d_2 :: p_1 : p_2 \quad (1)$$

$$v_1 : v_2 :: p_2 : p_1 \quad (2)$$

The equation shows that if the temperature of a gas is kept constant the volume is inversely proportional to the pressure. This is called the law of Boyle and Mariotte from its two independent discoverers, of whom Boyle seems to have been the first. As an example of Boyle's law, if any empty glass, or diving bell, be inverted over water, then submerged deeper and deeper, the air within it will shrink with increase of pressure, its volume becoming one-half when the pressure is doubled, one-third when the pressure is trebled, etc., if the temperature of the water is constant at different depths. In particular, if the pressure changes by one unit, the corresponding change of volume is $1/P$ part of that volume. For example, if a captive balloon is anchored in air at constant temperature, while the barometric pressure changes from 30.0 inches to 30.1 inches, the volume of the balloon will contract $1/300$ part of itself.

Until within comparatively recent times Boyle's law was supposed to be absolutely true for all gases at all pressures, but Despretz obtained results incompatible with the law. He took two graduated glass tubes of the same length, and filled one with air and the other with the gas to be examined. These tubes were placed in the same mercury trough, and the whole apparatus immersed in a strong glass cylinder filled with water. By means of a piston moved by a screw which worked in a cap at the top of a cylinder, the liquid could be subjected to an increasing pressure, and it could be seen whether the compression of the two gases was the same or not. The apparatus resembled that used for examining the compressibility of liquids. In this manner Despretz found that carbonic acid, sulphuretted hydrogen, ammonia, and cyanogen are more compressible than air; hydrogen, which has the same compressibility as air up to 15 atmospheres, is then less compressible. From these experiments it was concluded that the law of Boyle was not general.

In some experiments on the pressure of vapours, Dulong and Arago had occasion to test the accuracy of Boyle's law. The method adopted was exactly that of Boyle, but the apparatus had gigantic dimensions.

Dulong and Arago experimented with pressures up to 27 atmospheres, and observed that the volume of air always diminished a little more than is required by Boyle's law. But as these differences were very small, they attributed them to errors of observation, and concluded that the law was perfectly exact, at any rate up to 27 atmospheres.

The experiments of Regnault (1847) on the same subject were distinguished by the extreme care and attention to small sources of error with which they were carried out. Experiments were conducted in such a way that the pressure was observed when the gas filled the tube and also when the volume was reduced by compression to about half. If P, V are the pressure and volume of the gas when filling the tube, and P_1, V_1 the corresponding values for the half tube, $PV = P_1V_1$, supposing Boyle's law to hold.

If $\frac{PV}{P_1V_1} > 1$, or $\frac{PV}{P_1V_1} = 1 + e$, the gas is more compressible than Boyle's law requires.

If $\frac{PV}{P_1V_1} < 1$, or $\frac{PV}{P_1V_1} = 1 - e$, the gas is less compressible than it would be in accordance with the law.

Fig. 16 shows the value for e for various gases at various pressures.

These experiments show that the law of Boyle can be used with great accuracy for calculations in ballooning but will not be as correct in compressing hydrogen in bottles for field use as gas is usually forced into the bottles to a pressure of 100 to 125 atmospheres.

Charles Law (Temperature). When the pressure of a gas is kept constant, the volume is directly proportional to the absolute temperature and the density inversely proportional to the absolute temperature.

$$d_1 : d_2 :: 460.6 + t_2 : 460.6 + t_1 :: T_2 : T_1 \quad (3)$$

$$v_1 : v_2 :: 460.6 + t_1 : 460.6 + t_2 :: T_1 : T_2 \quad (4)$$

This equation shows that if the pressure of a gas is kept constant, the volume is proportional to the absolute temperature. This is the law of Charles and Gay Lussac, so called from its discoverers, of whom Charles is thought to have been the first. As an example of this law, if a captive thin rubber balloon is heated, or cooled, its volume will vary directly as its absolute temperature. In particular, if the temperature is changed one degree, the volume changes $1/T$ part of itself where T is absolute temperature.

For example, if the temperature of a balloon in air of constant barometric pressure is heated from 300° C. to 301° C., its volume will expand 1/300 part of itself.

Absolute zero in the metric system is 273° below 0° C. (freezing) while in the English system it is 460.6° F. below 0° F. or 492.6° F. below freezing.

When the pressure of a gas is kept constant its volume increases $\frac{1}{273}$ ($\frac{1}{492.6}$ English system) of its value at 0° C. (32° F.) for each 1° C. (1.8° F.) rise in temperature and vice versa when the volume of a gas is kept constant its pressure increases $\frac{1}{273}$ ($\frac{1}{492.6}$ English system) of its value at 0° C. (32° F.) for each 1° C. (1.8° F.) rise in temperature.

Boyles & Charles Laws Combined. Boyles law gives the relations that volume varies inversely as the pressure while with Charles law the volume varies directly as the absolute temperature. Combining these relations we have:

$$V \text{ varies as } \frac{T}{P} \quad \text{or } P V = RT \quad (5)$$

which is the fundamental gas formula P being the pressure, R the numerical constant for the gas in question and V the volume of a given portion of gas at the absolute temperature, T.

To find the value of R in this equation transpose and substitute specific values for P V and T as indicated by subscripts zero.

$$R = \frac{P_0 V_0}{T_0} \quad (6)$$

$$\text{Combine (5) and (6)} \quad \frac{V}{V_0} = \frac{P_0 T}{P T_0} \quad (7)$$

Now as the density d equals the weight W divided by its volume V

$$\text{then} \quad d = \frac{W}{V} \quad (8)$$

In like manner when this same weight of gas has changed in volume to V_0

$$d_0 = \frac{W}{V_0} \quad (9)$$

$$\text{Substituting (8) and (9) in (7)} \quad \frac{d}{d_0} = \frac{P T_0}{P_0 T} \quad (10)$$

From (7) if we have a certain known volume of gas V_0 at barometric pressure P_0 and temperature T_0 we can find the volume V at any other temperature and pressure by mere substitution.

For example a balloon has a capacity of 10,000 cubic ft. at 70° F. and 30" of mercury pressure and it is required to determine its volume at 60° F. and 25" pressure.

$$\text{Substituting in (7) we have} \quad V = V_0 \frac{P_0 T}{P T_0} = 10000 \frac{30 \times (460.6 + 60)}{25 \times (460.6 + 70)} = 11,820 \text{ cu. ft.}$$

If the density of a gas at 70° F. and 30" pressure is .005 lbs. per cu. ft. and its density at 60° F. and 25" pressure is desired formulæ (10) would be used as follows:

$$d = d_0 \frac{P T_0}{P_0 T} = .005 \frac{25 \times (460.6 + 70)}{30 \times (460.6 + 60)} = .00423$$

In the same way the temperature or pressure could be calculated if the other quantities are known.

It is a general observation in physics that a given portion of matter is of constant mass, however, its pressure, volume, temperature, and other conditions may vary. In particular, the mass or weight of a given portion of matter always equals the product of its mean density and volume since density is the weight per unit volume. Expressing this law algebraically:

$$d V = W \quad (11)$$

If mass W be considered unity the equation takes by form of the following interesting relation: $d = \frac{1}{V}$

By means of the various foregoing equations, the value of any one of the four quantities p, V, T, d representing respectively the pressure, volume, absolute temperature and density may be obtained in terms

of any two of the others. If then any two of the quantities is observed, the others can be at once computed. If, for example, the pressure and temperature of dry air be observed for any point, its density can be computed from the formulæ, also its volume per pound weight, and thence its volume for any weight. It is important therefore to be able to measure satisfactorily at least two of the four quantities. In the usual studies of the atmosphere the pressure and temperature are observed directly by instruments too well known to require description here.

Moisture. By moist air is meant a mixture of dry air and aqueous vapor in the form of an invisible elastic gas. The definition does not comprise air containing visible steam, or mist, or cloud, but clear moist air such as one ordinarily breathes. The study of this mixture may be preceded by a brief account of the gaseous properties of the vapor alone.

If water in sufficiently small quantity be introduced in a vacuum bottle at any ordinary temperature, it will promptly evaporate, forming an invisible gas known as aqueous vapor, filling the bottle and exerting a uniform pressure on its walls, except for the minute difference at top and bottom due to gravity. The vapor weighs 0.622 as much as dry air having the same volume, temperature and pressure, or quite accurately $\frac{5}{8}$ as much. It obeys all the laws given above for ordinary gases and dry air. But it has one singularity; at ordinary atmospheric temperatures, it cannot be indefinitely compressed without condensing to a liquid. In this respect it differs from the chief components of the atmosphere, which at ordinary temperatures can endure indefinite pressure without liquefaction. The ammonia and carbon dioxide in the air can, it is true, be condensed by pressure at their usual temperatures, but not by such pressures as occur in the free atmosphere, thus still leaving aqueous vapor the one singular constituent.

Reverting to the behavior of the water in the assumed vacuum bottle at fixed temperature, it may be observed that the pressure of the invisible vapor is directly proportional to the amount of liquid evaporated. In other words, for any fixed temperature the vapor pressure is directly proportional to its density. When this density reaches a certain definite amount, dependent solely upon the temperature, no further evaporation will occur, unless some of the vapor condenses. The pressure of saturation for that temperature has been reached, and any attempt to increase the pressure, by diminishing the volume of the vapor, will cause liquefaction at constant temperature.

If, however, the space is not saturated, the mass of vapor present may be expressed as a percentage of the amount required for saturation at that temperature. This percentage is called the relative humidity. Thus if the relative humidity is seventy per cent., the actual mass of water vapor present at the observed temperature is seventy per cent. of the maximum that can exist in the given space, at the given temperature. In other words, the relative humidity is the ratio of the actual to the possible humidity at a given temperature.

In like manner, for any given vapor pressure there is a definite saturation temperature, known as the dew-point. If with constant pressure the vapor is given various temperatures higher than the dew-point, it will remain gaseous and invisible; but if it falls in temperature to the dew-point, liquefaction occurs, and drops of water appear on the inner wall of the vessel. Further cooling will entail still further liquefaction and reduction of pressure; for, the lower the temperature the less the possible mass and pressure of saturation. But for all temperatures, down to freezing and considerably below, some vapor exists, and obeys the same laws as at higher temperatures. When, however, saturation occurs below freezing, the vapor may be precipitated as snow instead of water. This is a familiar phenomenon in the free atmosphere.

The actual mass of water vapor present in a cubic unit of space is sometimes called the absolute humidity. A formula giving the absolute humidity f , in kilograms per cubic meter, for any observed temperature t , and vapor pressure e , may be written as follows:

$$f = 0.00106 \, e / (1 + 0.00367 \, t)$$

in which e is the vapor pressure in millimeters of mercury, and t is the common Centigrade reading. As an illustration of the actual values of the pressure, temperature and density of saturated water vapor, for various conditions, the following table is presented:

TABLE 1
Temperature, Pressure and Density of Aqueous Vapor, in Metric Measures.

Temperature, Centigrade.	Pressure, Millimeters.	Density, Kilos per Cubic Meter.
—25	0.61	.557
—20	0.94	.892
—15	1.44	1.395
—10	2.15	2.154
— 5	3.16	3.244
0	4.57	4.835
+ 5	6.51	6.761
10	9.14	9.329
15	12.67	12.712
20	17.36	17.117
25	23.52	22.795
30	31.51	30.036
35	41.78	39.183
40	54.78	
45	71.36	

Now by Dalton's law, each gas or vapor in a mixture of several behaves as if it were alone. Thus if the foregoing experiment be conducted in a bottle containing various gases chemically inert to water, the same mass of water will be evaporated, and exert the same uniform pressure, in addition to those exerted by the gases. Now the density of each gas or vapor present, will equal its mass divided by its volume, and the density of the mixture will equal the total mass divided by the volume. Furthermore, it is well known that aqueous vapor is less dense than dry air at the same temperature and pressure. From this it is at once evident that moist air, which is merely a mixture of dry air and aqueous vapor, must be lighter than dry air at the same temperature and pressure. This is true whether the two fluids compared be in closed vessels or in the free atmosphere.

Accordingly in all precise dealing with the free air, whether involving its buoyancy, its resistance, its energy or any other mass function, its density as affected by the humidity must be taken into account. This can be computed from the observed pressure, temperature and relative humidity as revealed by well known instruments, the barometer, thermometer and hygrometer. Thus from the observed temperature and relative humidity, the mass of vapor present per cubic meter is read from Table 1, the reader, of course, multiplying the given tabulated mass by the observed percentage of humidity. To this aqueous mass must be added the mass of dry air present. Then the total mass per cubic meter is the density.

Various formulæ are available for computing the density of moist air from the readings of the three instruments mentioned above. Also, tables have been worked out giving the density without further calculation. Moreover, the density of free air may be directly measured, accurately enough for most purposes, by means of a densimeter. A simple formula for finding the density of moist air is as follows:

$$p = 0.465 (b - e)/T$$

in which b, e, are the pressures in millimeters mercury respectively of the moist air and its vapor, as revealed by the barometer and hygrometer.

In practice no great error will be made in assuming the relative humidity to be fifty per cent. For the moisture content never exceeds five per cent. of the mass of the moist air, and hence in assuming a fifty per cent. relative humidity, when there is actually a maximum or minimum humidity, the greatest possible error in estimating the moisture content is 2.5 per cent. of the mass of moist air. Now if 2.5 per cent. of a mass of air be assumed to be aqueous vapor when all is really dry air; or conversely if 2.5 per cent. of the whole mass be assumed as dry air when it is really aqueous vapor, an error of much less than 2.5 per cent. is made in estimating the true density. No error at all would ensue if both air and vapor were of the same density; but since one is $\frac{5}{8}$ as heavy as the other, the possible error is $\frac{3}{8}$ of 2.5 per cent., or 1 per cent. This is a negligible quantity in all mechanical considerations, except where great accuracy is required.

Adiabatic and Isothermal Conditions. As this subject has much to do with heat it is well at this point to explain what heat is. Two theories as to the nature of heat have been propounded.

On the first theory, heat is a subtle fluid which surrounds the molecules of bodies, and can pass from one body to another. The entrance of this substance into our bodies produces the sensation of warmth, its egress the sensation of cold.

On the second hypothesis the heat of a body is caused by an extremely rapid vibratory or rectilinear motion of its molecules; and the hottest bodies are those in which the energy of this motion is greatest. The heat which a body contains is measured by the energy of motion of all its particles. To increase the temperature of the body is to increase this energy; to lower the temperature is to decrease the energy.

The general effects of heat upon bodies may be classed under three heads. One portion is expended in raising the temperature of a body; that is in increasing the kinetic energy of its molecules. A second portion of the heat communicated to the body may be spent in altering the relative positions of the atoms within the molecules. These two effects are classed as internal work. The third portion is spent in increasing the volume, and so doing work against internal pressure. The heat or work required for this is called the external work. This third portion is what we have most to do with in ballooning.

Temperature is not heat but the measure of the hotness in a body. It is not the measure of the quantity of heat in a body for a cup of water may have the same temperature as a pail full of water, still the quantity of heat in the pail far exceeds that in the cup.

A body is said to undergo an isothermal transformation when it changes in such a way that there is no change in temperature, in other words all the heat formed by pressure or any other cause is either radiated off or converted into energy, leaving a constant temperature. Such a change takes place when water is changed into steam or ice. An adiabatic transformation takes place when there is no gain or loss of heat during the change.

A good example of adiabatic compression is given in the pneumatic syringe. This consists of a glass tube with thick sides closed hermetically by a leather piston. At the bottom of this there is a cavity into which is placed a small piece of cotton, moistened with ether. The tube being full of air, the piston is suddenly plunged downward; the air thus compressed disengages so much heat as to ignite the cotton, which is seen to burn when the piston is rapidly withdrawn. The heat does not escape thru the thick, badly conducting glass walls. The ignition of the cotton in this experiment indicates a temperature of at least 300°C .

An example of adiabatic expansion or cooling is given in the cold air machine. A steam engine is used to compress the air from atmospheric pressure to a pressure of about 4 atmospheres. Due to the compression as in the pneumatic syringe the temperature rises to 130° or 140°C . The air then passes to the cooler in which its temperature is reduced to ordinary temperature and the condensed moisture drained away. After the air has further dried it passes, still at the high pressure, to the expansion cylinder and in expanding cools to about -60°C . The residual aqueous vapor is deposited as snow. The air is now circulated thru the various chambers to be cooled.

It has been seen that the state of a given mass of any gas depends only on two independent variables; for the characteristic equation of a gas is $PV = RT$ and from this it is clear that if the pressure and volume of a given mass of gas are given, its temperature can only have one value. Similarly, if the temperature and volume are given, the pressure is fixed, and so on. An isothermal curve of a gas is a curve which gives the relation between the pressure and volume at any constant temperature. It is usual to represent the pressure along the vertical axis and the volume along the horizontal axis, and the expression $p v = \text{const.}$ informs us that the curve has the form of a rectangular hyperbola.

In Fig. 17 the curve LL_1 represents the behaviour of a certain quantity of the gas at constant temperature t_1 . Whatever be its volume and pressure, the state of the gas will be denoted by some point on this curve, the form of the curve being fixed by the fact that $Op_1 \times Ov_1 = Op_2 \times Ov_2$, wherever A and B may be. If the temperature is raised and kept constant at t , we get another isothermal line MM_1 , which will be farther away from the axes, since for a given volume the pressure will be greater than at the lower temperature. Thus, for a perfect ideal gas the isothermal lines are a series of rectangular hyperbolas farther and farther away from the axes as the temperature is higher. For a real gas, far removed from its temperature of liquefaction, the isothermal lines do not differ materially from those shown, but the deviation from the hyperbolic form becomes marked as the temperature of liquefaction is approached.

If the changes of volume and pressure of a substance (say a gas) occur in such a way that no heat is gained or lost, they are said to take place adiabatically, and the curves exhibiting the variations of pressure and volume under these conditions are called adiabatic lines.

In Fig. 18 let Q_1, Q_2, \dots be adiabatics of a gas, and let B denote the state of the gas at temperature, pressure, and volume, t_2, p_2, v_2 respectively. If the volume is reduced to v_1 and no heat escapes, the temperature will rise and the pressure become $p_1 (= Op_1)$ greater than it would have been with isothermal contraction. Thus the adiabatic through B is steeper than the isothermal, and so for other points. The equation to an adiabatic line, that is, the relation between p and v which characterizes it, is $pv^C = \text{const.}$, where $C = C_p/C_v$, the ratio of the specific heat of a gas at constant pressure to its specific heat at constant volume.

The value of the ratio C_p/C_v for any gas may be obtained from determinations of the velocity of sound in the gas. In the case of air this ratio is 1.41, for nonatomic gases, viz: mercury vapor, argon, krypton, etc., it is 1.66, for Oxygen Nitrogen, Hydrogen and Carbonmonoxide 1.41 and for Carbondioxide 1.31.

From the adiabatic equation $pv^C = \text{const.}$, if the volume and pressure be known at one altitude, the volume or pressure can be easily determined for another altitude if either the pressure or volume is known at that altitude. As the pressure is most easily determined, let us assume for example, that it changes from 30 inches to 29 inches which is approximately equivalent to a change of altitude of 1000 ft. now if we start with 1000 cu. ft. of hydrogen at a pressure of 30" and rise adiabatically 1000 ft. or till the pressure becomes 29" our new volume is found as follows:

$$\begin{aligned} \text{At start } PV &= \text{Constant} \\ 30 \times 1000 &= K \\ \text{Adiabatic rise } pv^C &= \text{constant} \\ 29V^{1.41} &= K \end{aligned} \quad (12)$$

$$\text{Therefore, } V^{1.41} = \frac{30 \times 1000}{29}$$

solving for V and substituting in equation (5) assuming T as the absolute temperature of the gas at start, the adiabatic temperature change of the gas for a 1000 ft. change of altitude can be found. For Hydrogen this change in temperature is 5.4° F. or 3° C. that is to say if a balloon filled with hydrogen rises at such a rate that no transfer of heat takes place between the gas in the balloon and the atmosphere the change in temperature of the gas in the balloon will be 5.4° F. or 3° C. for each 1000 feet change in altitude. If the balloon rises slowly the gas expands adiabatically just the same and endeavors to decrease in temperature at the rate of 5.4° F. for each 1000 feet. But, however, the rise is so slow, and the surface of the balloon so great that the exchange of heat between the gas and the atmosphere tends to equalize the temperatures so that the temperature of the gas in a balloon does not decrease at the rate of 5.4° F. per 1000 ft., except in the sole case of neutral atmosphere when the temperature gradient of the air is the same as the adiabatic expansion, in which case there can be no transfer of heat.

When a balloon rises rapidly its contents will expand adiabatically, pushing the envelope out in all directions against the static pressure of the embracing atmosphere. Thus it will do work and rapidly cool. But if it rapidly sinks it will contract adiabatically and grow warm, owing to the work done by the surrounding air in compressing it. A like thing occurs when a great volume of air rises or sinks quickly in the free atmosphere. In this case the change of temperature is about 6° C. for each kilometer change of level, so long as the air remains unsaturated. A familiar example of this effect in Nature is manifested when an uprushing column of moist air chills, and precipitates moisture, forming a cloud toward its top. Thus a lone thundercloud in a clear sky may mark the upper part of such a column, or upward vortex in the air. And contrariwise, a descending column may absorb its visible moisture, causing it to become clear aqueous vapor, and thus vanish from view.

Flow of Gases. It is often advantageous to know the length of time that is required to discharge a certain volume of gas thru the gas valve, or the volume of gas equivalent to a certain weight of discharged ballast. Referring to equation (5) we have

$$V = \frac{RT}{P}$$

in which (considering the English system); T the temperature of gas in degrees Fahrenheit, P the atmospheric

pressure in pounds per square foot, R is the gas constant of gas under consideration, and V is the volume of gas in cu. ft. equivalent to 1 pound of ballast discharged. Another equation containing this volume V is obtained if we know the effective area of the valve A in sq. ft., the velocity of flow of gas v in ft. per second thru this orifice, and the time t

$$V = Avt \quad (13)$$

Again referring to our physical laws we have

$$v = C \sqrt{2gh} \quad (14)$$

in which C is a constant, g is 32.2 the acceleration of gravity and h is the head of air at the base of the appendix in ft. reduced to its equivalent height of the gas. C can be taken as .6 with reasonable accuracy, this quantity varying but slightly in the range of this work. Thus considering d as the density in pounds per cu. ft. the relation reduces to

$$v = .6 \sqrt{2 \times 32.2 h \frac{(1-d)}{d}} \text{ or } 4.8 \sqrt{h \frac{(1-d)}{d}} \quad (15)$$

As the volume of gas equivalent to 1 lb. of ballast depends upon the relative weight of the air and gas formula (5) reduces to

$$V = \frac{RT(d)}{P(1-d)} \quad (16)$$

Now equating the two values of V in (13) and (16) and substituting v in (15) we have

$$t = \frac{KRT \sqrt{d}}{PA \sqrt{h} \sqrt{1-d}} \quad (17)$$

This equation is not as formidable as it appears for as soon as any specific gas is considered the quantities containing d are simplified. A is simply the effective area of the valve orifice in sq. ft., P the barometric pressure in inches of mercury, R the constant for air, K an experimental constant, T the absolute temperature Fahrenheit and h the distance from the valve at the top of the balloon to the bottom of the appendix or whatever distance is considered as the head. For any gas this formula takes the form

$$t = \frac{.41T \sqrt{d}}{AP \sqrt{h} \sqrt{1-d}}$$

This formula is independent of barometric pressure, temperature, kind of gas, size of balloon or size of valve and gives the time in seconds to discharge gas equivalent to one pound of ballast. For hydrogen the formula simplifies to

$$t = \frac{.12T}{AP \sqrt{h}}$$

For any other specific gas a similar formula can be worked out.

Effect of Sun's Rays. It is the heat from the sun that warms the earth's surface, the air and this gas in the balloon. It might be expected that the temperature of the gas in a balloon floating in the air would be the same as the temperature of the atmosphere itself in the same way that when any body is in a fluid the temperature of the body and the fluid soon become the same. This is not the case, however. A balloon may have exactly the same temperature as the atmosphere, but a short time after the sun's rays have played on the balloon, the temperature of the gas in the balloon increases much higher than the atmospheric temperature. In the case of a rubberized balloon fabric this increase may be as much as 50 degrees F., while in the case of a varnished balloon a maximum increase of 90 degrees F. can be obtained. This increase in temperature is due to the light rays being changed to heat as it passes thru the fabric. It is this same effect that takes place in a green house or a tent. On a sunny day the temperature in a green house or a tent is always higher than the surrounding air.

When a balloon passes under a cloud the sun's rays are cut off from the balloon and soon there is a contraction of the gas in the balloon due to the decrease in temperature.

Chapter III

Gases Used in Ballooning

Most people think that it is the gas in a balloon that causes the balloon to rise, but this is not the case. In fact, were it possible to remove the gas from the balloon altogether, forming a vacuum still retaining the spherical shape of the bag, the upward force of the bag would be greater than when filled with any gas whatsoever. This shows that it is not the substance within the balloon that gives its ascensional power, but the air outside the balloon instead. In a similar way it is not due to any lifting power in a block of wood that it floats upon the water but due to the buoyancy, or lifting power, of the water.

Many years ago, Archimedes discovered the principle that every body immersed in a fluid is buoyed by a force equal to the weight of the fluid displaced. Now, naturally the lighter the body the greater the net lift. A block of wood floats because it is lighter than an equal volume of water, a piece of iron sinks on account of its weight compared with water. A balloon rises because its entire weight, including the weight of gas, is less than the weight of the air displaced by the gas bag, hence it can be seen that the lighter the gas used to fill the balloon the more useful load can be lifted. Below will be given a brief description of the various gases used in ballooning.

HOT AIR

Heated air was the first gas used in ballooning, and is still used to a small extent at fairs and exhibitions. The question may be asked how the atmosphere could lift a bag filled with the same material. Let me direct you to a radiator; the heated air rises. Why? Because heated air is lighter than cool air. Almost all substances expand and have less weight per unit volume when heated. Air when heated from 60 degrees F. to 150 degrees F. will have a lift of about $1/30$ of a pound per cu. ft. Hence, it is the increase in the weight of the air displaced by the bag, over the weight of the air in the bag, that causes the balloon to ascend.

To be sure, as the balloon rises rapidly to the cooler altitudes and no additional heat is applied, it radiates its heat very rapidly, hence, when it has reached its maximum altitude it has quite a downward force, which gradually increases until the balloon now filled with almost cold air having very little lift descends to the earth with a great velocity. For this reason it is not safe to descend with a hot air balloon, hence as has been noticed at county fairs, the descent is always made by parachute, a weight on the top of the balloon turning the balloon upside down and assisting the rapid deflation and descent to the earth so that the balloon will not drift too far from the starting point.

The only point in favor of the use of heated air as an ascensional power in ballooning is the fact that it is easily and quickly produced and requires no plant to produce it, a fire in a hole producing the necessary heat.

NATURAL GAS

Natural gas comes from the earth in large quantities in Pennsylvania, Ohio and West Virginia. It consists of about 90% marsh gas (CH_4) and 10% of other hydro-carbons. It is a very explosive gas, being similar in composition to the fire damp found in coal mines. It is a cheap gas, but has very little lifting power being a fairly heavy gas. Its lift is about equal to that of air heated from 60 degrees F. to 150 degrees F. Its specific gravity averages about .66.

WATER GAS

The next gas of importance in ballooning is water gas so called because it is made from water or steam. It constitutes the basis of the illuminating gas used in most cities at the present time. Super-heated steam is passed through red hot carbon, either in the form of coke or hard coal, giving the following reaction: $\text{H}_2\text{O} + \text{C} = \text{CO} + 2\text{H}$. This combination of CO and H being water gas.

The retort used for this purpose is made of iron and usually filled with coke to a height of 4 ft. An air blast is passed through this coke bed at a pressure of 20" of water for from 1 to 2 minutes, or until the temperature of the coke rises to from 2700 degrees F. to 2850 degrees F. This pressure is maintained in

order that the carbon may be burned to CO_2 instead of CO . The air blast is now turned off, the top of the retort closed and dry steam at a pressure of 100 lbs. per square inch passed up through this bed of highly heated carbon. As stated before, this heat breaks the water or steam into its elements H and O, the O uniting with the C of the coke, forming CO . This operation continues for from 5 to 7 minutes, depending upon the temperature of the coke. When the coke has cooled somewhat CO_2 is formed instead of CO so that the steam is shut off and the air blast again applied and the above process repeated. As the coke is continually consumed, more is added at the top while the retort is open and the air blast is being applied. Approximately 40 lbs. of coke are required to produce 1000 cu. ft. of water gas by this process.

The gas manufactured in this way contains the following impurities: Sulphur which comes from the coke, CO_2 which is formed in the water gas generator, undecomposed steam, heavy carbo-hydrates in the form of gas, and many others. In order to remove these impurities, the gas passes through several purifiers. (See Fig. 9). It first passes through the seal pot filled with water, which removes much of the tarry substances in the gas and at the same time acts as a check valve preventing any back flow of the gas. It then passes into the bottom of the scrubber and out at the top. The scrubber is nothing more than a tall iron tank filled with coke, brick or some like material with a spray of water at the top trickling down over it. The gas passing up through the wet coke is relieved of all its soluble impurities by the water, which passes on into the seal pot keeping it full to the required height and then runs into the sewer. The gas now passes into a holder before going on through the remaining purifiers in order that the gas may flow continuously through the remaining purifiers instead of intermittently as it is produced. From the holder it passes at about 4 inches of water pressure up through two purifiers filled with iron oxide (Fe_2O_3) which removes the H_2S from the gas forming FeS_2 .

The iron oxide will remove 50% of its weight of sulphur. Usually about once a year it is necessary to renew this oxide on account of the large amount of sulphur taken up. If exposed to the air, this iron sulphide gives up its sulphur and returns to the original oxide and may be used again.

The gas formed by this process is very cheap, requiring only coke and steam to produce it; but cheapness does not always give the characteristics desired. The gas so formed will give about the same net lift as natural gas having a specific gravity of about .66, hence is not a very desirable gas for ballooning. Besides this, it is a very dangerous gas to handle as it is extremely poisonous and very explosive.

COAL GAS

Coal gas is another gas greatly used in cities as an illuminating gas. This gas, however, is a much lighter gas, having a specific gravity of about .46. Its specific gravity varies greatly, the figure given being a good average. This is the best commercial gas known for ballooning, except hydrogen, and its cost of production is about the same as that for most methods of hydrogen production, except by the electrolytic process.

Coal gas is manufactured by heating clay or iron retorts filled with soft coal to a temperature of 1100 degrees or more (Fig. 10). From the retorts, tubes lead upward into a large main through which water is kept flowing. As the coal is heated, the gaseous products of distillation, together with some of the liquid and solid products, such as coal tar, ammonium compounds, sulphur and carbon dioxide,—pass into the water of the main and are there washed and a part deposited. The insoluble gases pass on thru several hundred feet of vertical pipes called condensers, beneath which there is water to remove more of the impurities. The gas then goes to the scrubbers and purifiers which are very similar to those described in the method of manufacture of water gas,—and then to the gas holder. By-products of destructive distillation of coal are coke and coal tar, with which we are all familiar. Coal gas, as it is usually obtained, is made up of the following gases: H 45%, CH_4 40%, CO 5%, luminous hydro-carbons 5%, CO_2 , N, etc., 5%.

HYDROGEN

Lastly, and by far the most important gas used in ballooning is hydrogen.

Properties. It is the lightest element known, hence the best for ballooning, weighing only .005621 pounds per cubic foot at 0°C . and 76 cm. pressure (32°F . and 29.92" pressure). One gram (15.43 gr.) at the same temperature and pressure equals 11.11 liters (678 cu. in.). It is a colorless, odorless, non-poisonous gas when pure, but the presence of impurities in the gas, even in minute quantities, often make the gas poisonous and gives it an odor often attributed erroneously to the gas itself.

Compared with other gases, hydrogen is soluble only to a very slight degree in water at 0° C; at 10° C, however, the solubility is much greater. Hydrogen liquifies at 220° C. and 20 atmospheres. The lowest pressure at which it is possible to liquify hydrogen is 14 atmospheres, and at this critical pressure a temperature of 240.8° C. is required. Hydrogen will burn in air when the percentage is as low as 4½, the flame traveling upward when ignited from below. As the percentage of H increases to 9, the flame will travel downward, or in any direction. Further increases in the percentage of H increases the intensity of the flame propagation, which, when very rapid and violent, is called an explosion. The flame propagation is greatly increased when the hydrogen is mixed with pure oxygen, which is not diluted with nitrogen, as is the air. For this reason, care should be taken not to compress hydrogen into bottles which have contained oxygen, unless they have been thoroughly cleaned.

Hydrogen can be manufactured in a great many ways,—some methods are cheaper than others,—others furnish purer hydrogen, some are more portable. Each method has its advantages and disadvantages; no one having all the advantages, as proved by the fact that all of the following methods are used more or less in the various parts of the world.

HYDROGEN MANUFACTURE BY IRON CONTACT PROCESS

The iron contact process was developed long ago by Coutelle and perfected by Fiffard in France, then developed commercially in England by Lane using several retorts for the iron. In Germany it was further developed by A. Messerschmitt, utilizing one large generative oven instead of many small retorts. The Messerschmitt regenerative oven is patented in the United States. The patents relate only to the oven and retorts. The steam and iron process is not patented. Plants of the multiple retort type producing 3500 cu. ft. of hydrogen per hour are now under construction at Pensacola and Langley Field. A Messerschmitt single retort plant is at present in use at the Goodyear Balloon School. This plant has a capacity of 3500 cu. ft. of hydrogen per hour, and steps are now being taken to increase this capacity to 7000 cu. ft. per hour.

The iron contact process for the production of hydrogen is often referred to as the regenerative steam and iron method, the principle being that when steam passes over red hot iron ore it is decomposed into its constituent elements, the iron ore absorbing oxygen from the steam and the hydrogen being collected. The chemical reaction is represented by the equation $2 \text{FeO} + \text{H}_2\text{O} = \text{Fe}_2\text{O}_3 + 2\text{H}$. To utilize this principle commercially, it is necessary to reduce the Fe_2O_3 back again to FeO and some of it reduces even to metallic iron. This can be done by passing a reducing agent through the ore which removes a part of the oxygen from the ore. The reason that the ore is not completely reduced to metallic iron is because it takes a much greater effort to separate the last of the oxygen from the iron.

Water Gas (CO and H) is the agent commonly used for this purpose of reducing the ore, by the following reactions: $\text{Fe}_2\text{O}_3 + 2\text{H} = 2\text{FeO} + \text{H}_2\text{O}$ and $\text{Fe}_2\text{O}_3 + \text{CO} = 2\text{FeO} + \text{CO}_2$. Water Gas must be purified before it is used to reduce the iron, the most detrimental impurity being sulphur in the form of H_2S , which unites with the iron, forming iron sulphide.

The hydrogen generator (See Fig. 11) is a vertical cylindrical iron shell inside of which is another thicker iron cylinder, the space between the two cylinders being filled with the iron ore, and the central portion with a honeycomb of fire brick. The fire brick and ore are heated to a high temperature by the action of the reducing agent and an air blast which is admitted near the top of the retort. After the ore and fire brick have attained the proper temperature and the ore has been sufficiently reduced, the air blast and water gas are turned off, and a jet of super-heated steam is passed up through the fire brick to increase the temperature of the steam still more, then down through the ore where it is broken up, the oxygen being absorbed and the hydrogen passing on. After the steam has passed through the hot ore for a few minutes, the ore drops in temperature to such an extent that the steam passes through without being decomposed. It is then necessary to shut off the steam and repeat the process already given.

Temperature is also a most important factor in the water gas generator, for if the temperature is too low, CO_2 is formed instead of CO , and will not act as a reducer.

The hydrogen, as it leaves the generator, contains many impurities. These are removed in the following manner (Fig. 11). The gas passes first through the seal which removes much of the tarry substances, some CO_2 and undecomposed steam, and also acts as a check valve to prevent any back flow of the hydrogen. From here it passes up through the scrubber filled with coke, down through which trickles a spray of water removing still more of the soluble impurities and then passes on to a small relief gas holder. As the process is an intermittent one, this relief holder is used to take up the pulsations and establish a constant

uniform flow of gas thru the remaining purifiers. The most injurious impurity commonly found in commercial hydrogen is sulphur, because of its action on rubber which is a constituent of rubberized balloon fabric. It gets into the gas through the impurities in the ore and the reducing gas. The following three purifiers are mainly for the purpose of removing this objectional impurity. The first two purifiers contain slatted shelves on which at first is spread Ca(OH)_2 mixed with sawdust to prevent packing and through which the gas must pass. CO_2 is removed by both of these purifiers, changing the Ca(OH)_2 into CaCO_3 . The first purifier also removes some of the H_2S , forming calcium sulph-hydrate. This calcium sulph-hydrate Ca(SH)_2 in turn absorbs all the CS_2 from the gas, forming CaCS_2 . As it is necessary to remove the CS_2 from the gas and as Ca(SH)_2 is a very expensive material to buy, this process is used to manufacture the Ca(SH)_2 , and after the first purifier has absorbed so much H_2S that it has been transformed to a great extent to Ca(SH)_2 , the order of the first and second purifiers is reversed so that purifier No. 1 filled with Ca(OH)_2 removes the CO_2 and H_2S forming CaCO_3 and Ca(SH)_2 . Purifier No. 2 filled with Ca(SH)_2 and some Ca(OH)_2 , removes the CS_2 and the rest of the CO_2 , forming CaCS_2 and CaCO_3 . Purifier No. 3 filled with iron ore Fe_2O_3 removes any sulphur compounds not previously removed; and purifier No. 4 filled with CaCl_2 or some other drying agent, absorbs all the moisture from the gas, leaving a gas which is from 98½ to 99% pure.

The hydrogen generators are originally filled with limonite or hematite (Fe_2O_3) which should be as porous as possible in order to expose greater surface to the action of the steam and water gas, and this ore should be free from sulphur compounds and other impurities. It is necessary to replace the ore in the generators about every 3 to 6 months. The frequency with which it is necessary to renew the ore depends upon whether the gas is produced continuously or not. If the gas is produced intermittently, allowing the ovens to cool, the ore is broken up by the expansion and contraction. Frequent action pulverizes the ore so that the steam and the water gas cannot be forced satisfactorily through the mass.

The impurities in the hydrogen produced and purified in this manner consist principally of nitrogen and carbon monoxide which are not injurious to balloon fabric. Hydrogen can be produced by this process at a cost of from \$5.00 to \$7.00 per thousand cu. ft. The more continuously the plant is operated, the less the cost per thousand cu. ft.

VITRIOL PROCESS

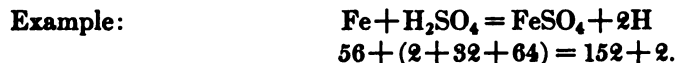
One of the oldest and best known methods for hydrogen production is the vitriol process. The action of sulphuric acid on iron or zinc evolves hydrogen as shown by the following chemical equation: $\text{Fe} + \text{H}_2\text{SO}_4 = \text{FeSO}_4 + 2\text{H}$.

It is essential that dilute acid be used for the reason that concentrated sulphuric acid forms a film of sulphate of iron on the surface, which is soluble in water but not dissolved by the concentrated acid. This process is so well known that a detailed description here seems unnecessary. The generating equipment can often be improvised by using substantial barrels or vats of wood or large glass or earthenware carboys, and lead pipes for conducting the acid. The caution to always pour the acid into the water and never the water into concentrated acid can not be repeated too often. Furthermore, when using improvised equipment or even specially constructed generators that are not positively gas tight, never strike a match or carry any open light such as a lantern near the generators.

It is found in practice that the washing and purifying of the gas by the usual methods does not entirely remove the water vapor carrying traces of sulphuric acid, which is most injurious to rubberized balloon fabrics; for this reason the vitriol process is not favored when it is practicable to secure hydrogen by other processes, but if it must be used, then special precautions should be taken such as multiplying the number of washers and purifiers and frequently changing the lime in the purifiers. Fresh unslaked lime is used in the purifier to absorb the moisture charged with traces of sulphuric acid which passes out of the hot generating tanks. The lime (CaO) has a great affinity for water $\text{CaO} + \text{H}_2\text{O} = \text{Ca(OH)}_2$ changing it to slaked lime (calcium hydroxide) upon absorbing the water. The lime also combines chemically with the sulphuric acid forming calcium sulphate ($2\text{CaO} + \text{H}_2\text{SO}_4 = \text{CaSO}_4 + \text{Ca(OH)}_2$). Greater purity of hydrogen can be insured when the weight of apparatus is unimportant, as in permanent installations, by adding in series more purifiers containing chemical substances such as caustic soda (NaOH) and calcium chloride (CaCl_2) both of which have property of absorbing moisture which is carried along with the hydrogen.

In order to determine the quantities of chemicals required to produce a certain quantity of hydrogen by any process, apply the atomic weights of the elements in the chemical equations in the manner shown below; for example, making the object of the computation 1,000 cu. ft. of hydrogen, it is necessary to deter-

mine first the number of cubic feet of hydrogen in one pound of the gas. This is found to be about 178 feet by taking 12.388 cu. ft. of air as weighing one pound and considering air as 14.4 times heavier than hydrogen, which figures are sufficiently accurate for this purpose.

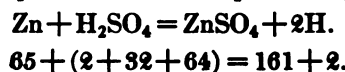


Then by proportion: 356 cu. ft. H : 1000 cu. ft. :: 56 lbs. Fe : X
 $X = 157 \text{ lbs. iron.}$

Similarly for sulphuric acid: 356 : 1000 :: 98 : X
 $X = 275 \text{ lbs.}$

It is seen from the foregoing that 157 lbs. of iron and 275 lbs. of sulphuric acid are theoretically required to produce 1,000 cubic feet hydrogen, but in estimating or purchasing these materials it is always advisable to increase the amounts by at least 5 and better 10 per cent. to allow for impurities in chemicals, incomplete chemical action, and losses of gas due to generators and pipes not being gas-tight in improvised apparatus.

The atomic weight of zinc is 65 and by a similar chemical equation it is found that theoretically 182.5 lbs. of zinc and 275 lbs. of sulphuric acid are required to produce 1,000 cubic feet of hydrogen.



At least 5 per cent. should be estimated above the theoretical amounts, for supplies of zinc and acid. Zinc usually contains some lead as impurity; the lead is not objectionable, but on the contrary, is said to assist in promoting rapid chemical combination due to galvanic action.

Using only the quantities of iron and acid according to the theoretical computation and assuming the cost of iron turnings at 2 cents per pound and acid at 3 cents per pound, the cost of materials alone to produce 1,000 cu. ft. hydrogen would be \$11.39.

ELECTROLYTIC METHOD

Hydrogen of greatest purity is obtained in commercial practice by the electrolysis of water, the hydrogen collecting on the negative electrode and the oxygen on the positive electrode where current enters the cell. A direct current of electricity is passed through water in a suitable cell which is provided with pipes for collecting both gases. The electro-chemical equivalent of hydrogen is .0000104 grams per coulomb which in larger units amounts to nearly 15 cubic feet of hydrogen for a current of 1,000 ampere hours. The theoretical electro-motive force required to dissociate water into its constituent elements is 1.47 volts between electrodes. Therefore, due to the internal resistance of the cell, if the voltage required is 2, then the computation shows that one kilowatt hour of electric power will produce $7\frac{1}{2}$ cubic feet of hydrogen.

The internal resistance of cells increases with the distance between the electrodes, and decreases as the size of the electrode increases. It varies also depending upon the nature and specific gravity of the electrolyte in the cell. Pure distilled water is a very poor conductor of electricity and extremely high E. M. F. would be necessary unless the conductivity is improved by adding suitable chemicals to the water. Ordinarily pure caustic soda (NaOH) is used, bringing the solution to specific gravity between 1.2 and 1.25 at 60° F. It is found experimentally that $2\frac{1}{4}$ pounds of chemically pure caustic soda are required to bring one gallon of distilled water to 1.25 specific gravity. This is about 17 per cent. caustic soda and is the point at which the solution has the greatest conductivity. Adding more caustic soda increases the internal resistance. Caustic potash (KOH) may also be used for electrolyte but a larger quantity is required and the present cost is much greater than that of caustic soda.

There are two general types of construction for electrolyzers, one being the unit type which consists of separate cells, each containing the positive and negative electrodes, connected electrically in series, the other general type being called by various names "bi-polar," "multiple-plate" and "filter press" types. These electrolyzers are usually constructed by assembling large plates very close together separating the positive and negative electrodes by sheets of asbestos; where 110 volt power is available these generators have 60 pairs of plates. The advantage of the multiple plate type over the unit cell type is principally lower first cost and less floor space required. The disadvantages being in greater maintenance cost and difficulty of preventing leakage of gas. Most of the electrolyzers made in the United States both unit type and bi-polar utilize a special weave of asbestos cloth as separator for the hydrogen and oxygen within the cell. The foreign made cells at Fort Omaha have a very fine wire gauze to separate the gases.

The quantity of hydrogen produced by this method is proportional to the amperage passed through the cell. For the American made electrolyzers the current varies from 35 to 1000 amperes, and for the Siemens cells at Fort Omaha the normal current is 1500 amperes. The E. M. F. required for each unit cell or for one pair of plates in the multiple type will average 2 volts, but depends largely upon the internal resistance of the cell, which in turn depends upon the size of the electrodes, distance between them, nature and specific gravity of the electrolyte and the temperature. It is observed in practice that in starting the plant when the cells are cold the E. M. F. per cell is often more than $3\frac{1}{2}$ volts, which reduces to less than 2 volts after the cells become hot.

As the water in the cells is converted into gas it must be replaced by pure distilled water. The quantity being 5.76 gallons for 1,000 cu. ft. of hydrogen. It is seldom necessary to add caustic soda to the solution and then only enough to replace the very small quantity which is carried off from the cells by the moisture with the hot gases, but even this vapor may be condensed and recovered to some extent by moisture traps of various kinds.

Most manufacturers of electrolyzers in the United States claim an output of $7\frac{1}{2}$ cubic feet of hydrogen per kilowatt hour. As shown in the preceding paragraphs this means an E. M. F. of not to exceed 2 volts per cell.

When it is possible to secure electric power at one cent per K. W. H. the cost of 1000 cu. ft. of hydrogen for power alone is \$1.57 (assuming motor generator efficiency of 85 per cent., and electrolyzer efficiency of $7\frac{1}{2}$ cubic feet hydrogen per K. W. H.).

The electrolytic plant installed by the army at Fort Omaha in 1908 consists of 30 large cells made by Siemens Bros. Company, Ltd., London, the normal current being 1500 amperes and the voltage varying from 4 to 22 per cell, depending upon temperature. The temperature should be maintained at 150 degrees F. Higher than that is likely to damage the insulation and produce an excess of moisture with the gas. Lower temperature increases the internal resistance and cost of electric power. Each cell produces 23.3 cubic feet of hydrogen per hour, a total of 699 cubic feet per hour for the 30 cells, equivalent to 16,776 cu. ft. per day of 24 hours for the plant.

SILICOL PROCESS

The production of hydrogen by dropping ferro-silicon into hot caustic soda is, in the French and British armies known as the "silicol" method; in Germany, it is called the Schuckert process, and for many years, the details of it were carefully concealed.

The chemical reaction producing hydrogen is between silicon and caustic soda without any change in the iron. The following chemical equation will serve to explain the process: $\text{Si} + 2\text{NaOH} + 2\text{H}_2\text{O} = \text{Na}_2\text{SiO}_3 + 4\text{H} + \text{H}_2\text{O}$. In Germany, it was customary to use pure or nearly pure silicon. In France, this method was developed for the military service by Capt. LeLarge and Dr. Jaubert; their generating apparatus being designed in three types; viz.: Auto truck transportable size, semi-fixed and sent for permanent installations. Ferro-silicon is used, being more easily secured and at less cost than pure silicon as in the Schuckert generators. The steel industry in this case uses large quantities of ferro-silicon containing 50 to 75% silicon. Experiments have shown that more satisfactory chemical action is secured by having the silicon content 80 to 85%. Commercial caustic soda of 97% NaOH is suitable.

Except in very cold weather the mixing of caustic soda with water produces sufficient heat to start the chemical combination of silicon and soda. It is necessary to agitate the solution constantly to secure best results and avoid sudden generation of large quantities of gas of explosive violence. The solution resulting from the chemical combination is sodium silicate, which may be easily drawn off at the bottom of the mixing tank.

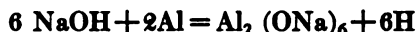
According to the chemical equation the production of one thousand feet of hydrogen would require 39.6 pounds of pure silicon and 112.3 pounds of pure caustic soda. The actual quantities which should be supplied depend upon the silicon content of the ferro-silicon and the percentage of purity of the caustic soda. An experiment conducted for the army determined that 58 lbs. of 80% ferro-silicon and $125\frac{1}{2}$ lbs. caustic soda would produce 1000 cu. ft. of hydrogen. Ferro-silicon at 15 cents per lb. and caustic soda at 3 cents per pound would bring the total cost for materials to \$12.46 per 1000 cu. ft.

Ferro-silicon may be stored without deterioration by moisture and without any special precaution for its care. The caustic soda must be protected from moisture and is usually supplied in air tight drums containing 100 pounds.

In connection with silicol generators, there are required washers and purifiers to remove from the gas the hot vapors carrying caustic soda solution. Field generators of this process should always be set up for operation near a stream or other ample supply of water. It is possible to design the generating equipment with radiators for cooling the circulating water for situations where water economy is important.

ALUMINUM CAUSTIC SODA PROCESS

During the war between Russia and Japan both armies used field hydrogen generators employing the chemical reaction of alkaline hydrates upon aluminum. Sodium hydrate (NaOH) ordinarily known as caustic soda, is preferred to the potassium hydrate on account of the lower cost of the soda. The chemical reaction taking place is represented by the following equation:



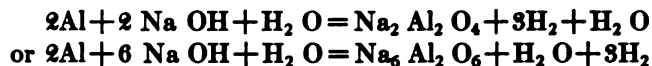
The generating apparatus was constructed in two types, one of small size installed on vehicles for rapid transportation and a larger size called "semi-fixed." An iron basket is filled with aluminum scrap, lowered into the solution of caustic soda, the cover being immediately clamped to make it gas tight. The gas passes from the generator to a washing and cooling device which removes the traces of alkaline matter.

In the generator the aluminum is attacked by the soda solution with great energy, the gas coming off rapidly and the liquid heating to the boiling point, but as the proportion of free soda in the solution diminishes, the rate becomes slower. In order to finish the gas production without delay, the generator is charged with caustic soda considerably above the theoretical requirement.

According to the theoretical computation, it is found that to produce 1,000 cubic feet of hydrogen there are required 224 pounds of caustic soda and 51 pounds of aluminum. With caustic soda at 3 cents per pound and aluminum at 50 cents per pound, the cost of the one thousand cubic feet of hydrogen by this process is \$32.22. The actual quantity of materials to be carried will be considerably in excess of 275 pounds and the cost per thousand more than the foregoing computation indicates, on account of the necessity for using an excess of caustic soda and the fact that commercial caustic soda contains impurities, the most common grade containing only 77% sodium hydrate.

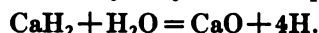
The aluminum and alkaline method has the advantage of requiring about 20% less weight of material than the vitriol process and both materials being dry are easily transported without the special care which is necessary for the transportation of sulphuric acid. Furthermore, the hydrogen produced is of greater purity, does not contain volatile hydrocarbons, nor the dangerous gases produced by combinations of hydrogen and arsenic.

U. S. patent was issued in September, 1901, for a modification of the aluminum-caustic-soda process. The inventor prepared the material by pouring molten caustic soda into a mass of aluminum in the form of powder, filings, or turnings, which was thoroughly mixed before the mass cooled. This mixture of material must be kept in sealed containers to avoid deterioration due to moisture in the atmosphere. When the mixed substance is placed in water the chemical reaction produces sodium aluminate and free hydrogen, probably according to the following equation:



HYDROLYTHE

"Hydrolythe" is calcium hydride (CaH₂) manufactured by heating pure metallic calcium in retorts containing hydrogen. To produce hydrogen it is only necessary to drop the granulated hydrolythe into water. Generating equipment similar to the ordinary acetylene gas outfits are suitable. The reason hydrolythe is not more extensively used is on account of its high cost. About ten years ago the Signal Corps purchased a sufficient quantity to conduct experiments, which confirmed all claims for it, but chemical manufacturers in the United States do not produce it at present. It will be seen from the following chemical equations that only 59 pounds of hydrolythe are required to produce 1,000 cubic feet of hydrogen.

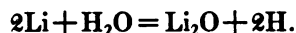


At 80 cents per pound for hydrolythe the cost of 1,000 cubic feet of hydrogen by this method would be \$47.20.

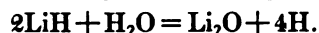
Pure sodium or lithium dropped in water will produce hydrogen, and it is possible to make hydrates of lithium the same as calcium which will similarly produce hydrogen upon contact with water. On account of the light weight of lithium this would be particularly desirable for field hydrogen generation, and experi-

ments are now in progress to determine whether it is practicable to manufacture lithium hydride at reasonable cost.

Dropping pure lithium in water would theoretically require only 40 pounds to produce 1,000 cubic feet of hydrogen:



And 22½ pounds of lithium hydride would produce 1,000 cubic feet hydrogen:



About ten years ago an American manufacturer proposed the use of lead compounds having great affinity for water known as "Hydrone A, B, and C," and experiments were conducted by the Signal Corps. It developed that the chemical reaction upon dropping the substance into an alkaline solution was so violent that the oxygen of the air above the generating tank would burn the hydrogen—the ignition being due to heat of the chemical action. This difficulty was overcome by manufacturing a lower grade which evolved hydrogen slowly. The low grade material was first dropped into the generator until the escaping gas had carried with it all oxygen above the water, then the high-grade substance was fed into the generator. On account of the extreme care that was necessary to avoid explosions with this method and the considerable weight of the hydrone, its further development for field hydrogen generation in the army was discontinued. One pound of hydrone produced only 2.88 cubic feet hydrogen at a cost of 6½ cents per cubic foot.

HYDROGENITE

The hydrogenite process is a modification of the "silicol" process already described. The chemical substances and reaction are the same as the silicol, but the materials are prepared and used in somewhat different manner. Pulverized ferro-silicon and caustic soda properly proportioned are thoroughly mixed and preserved in hermetically sealed cartridges, each containing 50 kilograms.

The field generators to use these cartridges consist of metal container slightly larger than the cartridge, having a lid which can be clamped down gas tight. After placing the cartridge in the apparatus, the top of the can is opened and the mixed powders ignited. Around the inside of the cylindrical burning oven in which the cartridge is placed, is a trough to contain a measured quantity of water. The heat produced by the burning of the chemicals quickly converts this water into steam, the silicon, soda, and water combining as in the previously shown equation describing silicol method.

Ignition may be started by a fuse or taper inserted in the powder or by placing on top a small quantity of some easily combustible powder in order to produce sufficient heat in one spot to start the combustion. The hydrogenite burns rapidly and without flame, like tinder; a cartridge of 50 kilograms being consumed in about ten minutes.

When the mixture is first ignited, the air in the chamber and products of combustion are permitted to escape until the pure hydrogen appears. The gas is passed through washing and cooling purifiers before being used.

It is learned that even with the greatest care generators are frequently destroyed by explosions, for which reason the process is not in general use.

HYDROGEN FROM WATER GAS

A German chemist developed and advocated some years ago the production of hydrogen for aeronautical purposes by first manufacturing water-gas in the usual manner, which consists principally of hydrogen and carbon monoxide, passing the water-gas over red-hot calcium carbide in the form of powder. The hot calcium carbide decomposes the carbon monoxide forming lime (CaO) and leaving carbon in the form of crystalline graphite. The inventor claims that minor impurities in the water-gas are almost entirely removed in the reaction, producing hydrogen of 99% purity. The report further stated that generating equipment was devised to produce 70,000 cu. ft. of hydrogen daily.

Hydrogen may also be separated from water-gas or coal gas by the fractional refrigeration process. Hydrogen liquefies under pressure at lower temperature than other common gases, so that from illuminating gas having a considerable percentage of hydrogen it is possible to cool and compress it with liquid air apparatus, drawing off first all other gases as they liquefy and leaving the hydrogen. This method is not in general use for commercial production for the reason that other methods offer more simple and more economical means of securing hydrogen.

The Electrical Review (Vol. 40) reported that M. D'Arsonval passed coal gas previously cooled to minus 80° C. through a Linde liquid air machine, obtaining 3,500 cu. ft. of hydrogen per hour, expending 12 to

15 h. p. Assuming coal gas to cost \$1 per thousand and containing 50% hydrogen, the cost of material would be about \$2 per thousand cu. ft. hydrogen, to which must be added approximately 60 cents per thousand for power, plus cost of expert attendance.

ALUMINUM-POTASSIUM CYANIDE PROCESS

A French chemist a few years ago advocated the generation of hydrogen for aeronautical purposes by mixing aluminum filings with pulverized bichloride of mercury and potassium cyanide. After these ingredients are thoroughly mixed, hydrogen will be produced by adding water. The powder has a density of 1.42 and must be kept in hermetically sealed cans. It is stated that experiments indicated 187 pounds of this material were required to produce 1,000 cu. ft. of hydrogen. The chemical reactions which take place should properly be represented by three or four stages, but may be sufficiently explained by the following single equation:



ACETYLENE PROCESS

In 1901 Mr. H. Houbon, a resident of England, invented and patented a process for making pure hydrogen from acetylene. He compressed the acetylene to 5 atmospheres in a Caillet steel bomb and ignited it by electric spark. The carbon precipitates in the form of fine soot leaving the pure hydrogen. It is stated that the process is without danger and calcium carbide for producing acetylene is very cheap, but it is not known that this process has ever been perfected for producing hydrogen in large quantities for aeronautical service.

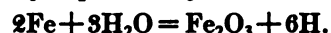
By computation it is found that 180 lbs. of calcium carbide are required to produce 1,000 cu. ft. of hydrogen by this method.



IRON AND WATER PROCESS

Recently an article in a German technical journal described a new method for securing compressed hydrogen of great purity. So far as known it has been employed only in laboratories, but it may be developed later on a commercial scale.

Powdered iron is mixed in water in a vertical steel cylinder, the liquid being subjected to a pressure of 300 atmospheres (4,410 lbs. per sq. in.) and the temperature raised to 350° C. The chemical reaction that takes place is sufficiently explained by the following equation:



from which it is seen that under this great heat and pressure the iron combines with the oxygen from the water, and the hydrogen may be removed at the top of the cylinder already compressed for storage in cylinders. The iron oxide may be easily reduced again to metallic iron, which is facilitated by its porous condition, due to the peculiar manner in which it is oxidized. Hydrogen obtained is said to have 99% purity, which can be further increased to 99.95% by being passed over charcoal. When iron contains sulphur, the sulphur is not attacked, but any carbon content in the iron is converted into carbon monoxide.

SILICO-ACETYLENE PROCESS

The silicides of calcium, barium and strontium (CaSi_2 : BaSi_2 : SrSi_2) are made in the electric furnace similar to the manufacture of calcium carbide. When calcium silicide is added to acidulated water, it is decomposed, leaving silico-acetylene in solution; the calcium oxide is precipitated. The solution is drawn off and evaporated leaving yellow crystals of silico-acetylene Si_2H_2 . When these crystals are added to alkaline solution such as caustic soda or potash, the silico-acetylene is decomposed, evolving hydrogen. It is reported that 163 lbs. of silico-acetylene are required to produce 1,000 cu. ft. of hydrogen.

DECARBURATION OF OILS

About four years ago the Scientific American described equipment developed by the German Army for the generation of hydrogen by the method of decarburizing hydro-carbon oils. The apparatus was designed for installation on two railway cars, the main part of the equipment consisting of two gas producers. To fire up these producers to the proper heat requires from one to two hours.

The producers are filled with coke which is heated to redness by air-blast. Crude petroleum or any petroleum distillates are first vaporized and then passed through the producer ovens containing the hot coke,

which decomposes the oil. After about twenty minutes the coke has been reduced in temperature so much that it is necessary to heat it again to redness by hot air blast. This requires only two or three minutes.

The gas produced is passed through water scrubbers and purifiers to remove sulphur. It contains considerable carbon monoxide which is removed by passing the gas through an oven, the details of which process are not stated. The resultant gas is said to be 98.4% hydrogen, 1.2% nitrogen, and 0.4% carbon monoxide and to have a specific gravity between 0.087 and 0.092.

Additional References on Hydrogen

ALLOYS

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TRANSPORTATION OF GAS

Nurse. Gas is often transported from one place to another by the use of the "nurse" when the distance is not too great. The "Nurse" is nothing more than a fabric container holding probably 5000 cu. ft. of gas. This bag is usually made cylindrical with hemispherical ends and equipped with ropes on either side for the purpose of transporting it from one place to another.

Bags of sand are attached to these ropes so that the weight of the sand almost equals the lift of the gas. In this way, the only force to overcome is that due to the wind.

In crossing wires, the first pair of ropes are thrown over the wires and caught again on the other side, then the second pair, etc., until the gas bag has been literally carried over the wires. The gas can be taken from the "nurse" in two ways, either by the application of pressure on the bag, or by having the outlet in the top of the bag and depending upon the lightness of the gas to leave the bag, or both.

Bottle. The most usual method of transporting gas is by the use of gas bottles. These bottles vary in size, the most usual size having a total height of about 5 ft. and an outside diameter of approximately

8 inches. These bottles are pressed from steel and have no seams. The wall of these bottles is from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch thick. When inflated to a pressure of 2000 lbs., which is the usual pressure to which these bottles are filled, they contain a quantity of gas which when released to atmospheric pressure has a volume of from 200 to 300 cu. ft.

A specially constructed needle valve is required to prevent the escape of gas at this high pressure.

When emptying these bottles a great decrease in the temperature takes place at the valve due to the sudden adiabatic expansion of the gas, causing frost, and even freezing the outlet completely shut cutting off the supply of gas and giving the impression of an empty bottle. The valve must be thawed out before the remainder of the gas can be obtained. This freezing can be eliminated and the entire quantity of gas discharged quicker by opening the valve only part way, hence keeping the gas temperature from dropping to such a low degree. After the pressure in the bottle has decreased somewhat, the valve may be opened wider.

For military purposes, trucks are arranged with shelves so that several layers of bottles can be transported at the same time; the bottles are all clamped in place so that they cannot jar about. In order to facilitate rapid gas bag inflation, all of the bottles of each row are connected to one main and the several mains connected together, so that all that is necessary to discharge the contents of perhaps two dozen bottles is to attach the inflation tube to this manifold and turn all the valves slightly. In this way, the Allies in Europe can completely layout, inflate and raise a 35,000 cu. ft. kite balloon into the air in 20 minutes.

Chapter IV

Physics of the Atmosphere*

For aëronautic uses the atmosphere may be regarded as a mixture of two substances, dry air and water. The first remains always in the gaseous state; the second shifts erratically through all possible states. Rain drops freeze or evaporate; sleet, snow, and hail evaporate or melt; the aqueous vapor condenses or congeals. Thus the world is wrapped in a dual sea, one part naturally serene, the other capricious, protean, and turbulent. Dry air, indeed, is a composite of many gases of vast concern in chemistry and biology; but in relation to aeronautics it is practically a single permanent gas. This placid element and its inconstant mate, so curiously mingled, constitute the medium whose flux and vicissitudes the aerial sailor has duly to learn before he can navigate with skill or safety. The whole water vapor in the atmosphere of our latitude in summer is equivalent to about one inch of rainfall.

But these aerial oceans, the moist and dry, are of very different depth. They commingle only in the lower levels of the atmosphere, whose qualities vary accordingly, both physical and transportation. While the dry air may reach up to more than a hundred miles, substantial enough to singe a meteorite, the sea of aqueous vapor is bounded practically by the shallow region of the visible clouds. Beyond the feather-like cirri, which just overtop the loftiest mountain peaks, there is scant, if any moisture. Never rain, nor cloud is there, nor tempest nor any great perturbation. Beyond the highest excursions of the cirri, at an elevation of some ten miles, stretches the deep ocean of eternal sunshine, of equable and nearly constant temperature. Into that zone of perpetual serenity no tumult of the nether atmosphere can penetrate; against the floor of the isothermal layer the cyclonic currents spread and dissipate. The upper air has, of course, a considerable drift, like a majestic river or stream of the sea, but never turmoil or tempest disturbs its stately march.

Incidentally and aside from its aeronautic interest, the composition of the atmosphere may be presented in fuller detail, showing the wide variations from level to level, and the manifold complexity of the fluid we daily breathe, not to mention the myriads of motes and germs inhabiting every inch of it. The gaseous components and their distribution are well exhibited in the following table (computed by W. J. Humphryes or Moore's Descriptive Meteorology), which represents an average condition:

TABLE II
Percentage Distribution of Gases in the Atmosphere

Height in Kilometers	Argon	Nitrogen	Water Vapor	Oxygen	Carbon Dioxide	Hydrogen	Helium	Total Pressure in Millimeters
150						99.73	0.27	0.0043
140						99.70	0.30	0.0048
130		0.02				99.64	0.34	0.0054
120		0.10				99.52	0.38	0.0060
110		0.40		0.02		99.16	0.42	0.0067
100		1.63		0.07		97.84	0.46	0.0076
90		6.57		0.32		92.62	0.49	0.0090
80		22.70		1.38		75.47	0.45	0.0123
70	0.02	53.73		4.05		41.95	0.27	0.0248
60	0.04	78.16		7.32		14.33	0.15	0.0810
50	0.08	86.16		10.01		3.72	0.03	0.466
40	0.16	86.51		12.45		0.88		1.65
30	0.22	84.48		15.10		0.20		8.04
20	0.55	81.34		18.05	0.01	0.05		39.6
15	0.74	79.56		19.66	0.02	0.02		88.2
11	0.94	78.02	0.01	20.99	0.03	0.01		168.
5	0.94	77.89	0.18	20.95	0.03	0.01		405.
0	0.93	77.08	1.20	20.75	0.03	0.01		760.

*Some portions of this chapter copied from "Zahm's Aerial Navigation."

Fixing attention first upon the gases other than water, it will be at once observed from the table that these gases show a very uniform mixture in the moist and turbulent region, while farther aloft the lighter of them tend to predominate in relative proportion. This uniformity of composition at the lower levels, which accords with experience, is due to the constant circulation and turmoil in that region. But for this constant agitation, the uniformity of mixture could not last. If the atmosphere were perpetually at rest throughout, or moving only in horizontal flow, each constituent gas would assume the same status and distribution as if the others were absent. Each, therefore, obeying Dalton's law of diffusion, would form an atmosphere of itself, independent of the others, and unaffected in density by them. Such a condition is assumed for the higher levels. The percentage distribution in the higher levels is calculated from the known elasticity and density of the gases, assumed as resting in perpetual calm at a constant temperature of -55° C. beyond eleven kilometers, or above the highest ascent of man, and, furthermore, as having at the earth's surface 1.2 per cent. moisture and a temperature of 11° C.

But only in the quiescent outersphere can that dynamic gradation be established or perpetuated. Below this lofty region is the sea of water vapor, mingled intimately with the dry air, and churned with it, yet not sharing its uniformity of distribution. Why this rapid diminution of moisture with elevation, as shown in the table? Because throughout the moist region the temperature falls rapidly—about 6° C. per kilometer ascent above the earth—thus chilling and precipitating the vapor, whose pressural resistance to liquefaction diminishes with waning temperature. The explanation is obvious; but why does it not apply as well to the other elements of the atmosphere; why do not the other gases present liquefy with falling temperature as well as the water vapor, which is merely water in the gaseous state? The question cannot be answered very profoundly, but an essential condition of liquefaction of any gas can be stated in learned phraseology, after the preliminary exposition of certain general properties of matter.

We may first set forth those general physical properties, then apply them to answering the above question. Every known substance may exist in either of three states, the solid, liquid or gaseous. For every substance there is a critical temperature above which it can exist only as a gas, and cannot be liquefied by any pressure, but below which a suitable pressure will cause liquefaction. Below its critical temperature a gas is called a vapor, above it a permanent gas. Now in the free atmosphere some of the gases are never below their critical temperatures and, therefore, cannot be liquefied by any pressure, without special cooling; others are sometimes below their critical temperatures and are then capable of liquefaction by sufficient pressure, which, however, is not always found in free space, but can be supplied by a compression pump; one other gas, that is water vapor, is always below its critical temperature in the free atmosphere, and therefore may always be turned into water by sufficient pressure at its actual atmospheric temperature. Such sufficient pressure in the water vapor actually occurs from time to time in all parts of the atmosphere from the earth's

TABLE III
Critical Temperature and Corresponding Pressure of Liquefaction for the Chief Constituent Gases of the Atmosphere

SUBSTANCE	Critical Temperature C.	Critical Pressure Atmosphere
Dry Air.....	—140	39
Nitrogen.....	—146	34
Oxygen.....	—118	50
Carbonic Acid.....	— 31	75
Argon.....	—120	51
Hydrogen.....	—242	20
Ammonia.....	—130	115
Water.....	+ 365	200

surface to the highest cirrus region, but more frequently in the nimbus levels, a mile or two above the earth. Thus at all parts of the lower atmosphere liquefaction of aqueous vapor is sometimes observed, either as mist or rain, snow or ice particles, and on the earth as dew or frost. In order to illustrate the above ideas by numerical citation, the accompanying table is given, showing the critical temperature and pressure of the chief gaseous constituents of the atmosphere.

A glance at this table shows that for the pressures and temperatures prevailing in our atmosphere most

of the constituents are permanent gases. The conspicuous exception is water which, when in the gaseous state, always exists as a vapor and never as a permanent gas, since it never even approaches the critical temperature. Fortunately for all life on earth the aqueous vapor condenses at very ordinary temperatures and pressures, else there would be no rainfall for irrigation and drinking. Fortunately also the other gases do not so precipitate, else the world might be flooded with liquid nitrogen and oxygen, entailing who knows what disastrous consequences.

After this digression on the composition of the atmosphere, we may henceforth regard the aerial ocean as a mixture of two substances, dry air and water; the first, a permanent gas; the second, a variable element, existing at times in either the solid, liquid, or vaporous state.

Having thus briefly examined the composition and certain gaseous properties of free air, both dry and moist, we may now study the atmosphere as a whole. We wish particularly to know of its distribution of temperature and pressure; of its general and permanent circulation; of its great periodic currents; of its vertical movements, and its minor local winds with their pulsations of velocity and direction. Fortunately much information is available, due both to governmental and private research, though this was collected more for purposes of meteorology than of aerial locomotion. Of late, however, attention has been given to the aeronautic study of the atmosphere, which will, it is hoped, prove valuable to the aerial navigator.

The movements of the atmosphere are due mainly to the sun's heat and to the rotation of the earth. The earth's internal heat and the moon's attraction are other minor agencies, but these may be neglected by comparison. The earth's rotation also would be ineffectual in modifying the aerial movements, except for the co-operation of the sun. Without this influence the atmosphere, always stagnant, would simply rotate with the globe, at constant angular velocity and uniformly graded density at various levels. This evenness of density for any level is broken by the solar radiation increasing the temperature and moisture, otherwise the air would remain practically at a standstill.

Though the moisture by its lesser density causes some lightening of the air at fixed temperature, this at most is hardly one per cent, as already shown and on the average is much less. Its effect, therefore, is equivalent to less than that caused by a rise of temperature of three degrees. But if precipitation occurs, an enormous amount of stored sunshine, or latent heat, is liberated and applied to warming the associated air. Thus each pound of vapor condensed may, by the release of its thermal store, heat more than a ton of air one degree in temperature, or more than half a ton of air two degrees, etc. The actual number of pounds of air at constant pressure, raised one degree Centigrade by the condensation of one pound of vapor at various temperatures, is given in the following table:

TABLE IV

Temperature of condensation	0°	25°	50°
Pounds of air heated one degree	2550	2480	2407

The sun then is father of the wind. By uneven heating of the atmosphere it disturbs the uniform density graduation that would otherwise exist. Thus abnormal pressures are generated which disturb the repose of the aerial sea, causing the fluid to flow from regions of excessive to regions of defective pressure. Hence the study of insolation¹ and temperature distribution is fundamental to the science of the winds.

Without detailed study, we may note the aggregate insolation received by the earth, at various latitudes, and its general effect on terrestrial temperature. The sun emits a nearly constant stream of radiation, from year to year, which plays continuously upon the earth as a whole, with an intensity which varies but slightly from month to month, due to the slightly varying distances of the earth from the sun. Owing to the sun's seasonal wandering across the equator, the insolation at any latitude varies considerably month by month, and the polar regions receive much more light than if no such wandering occurred. The total yearly insolation for every 5° of latitude is shown in the following table from Hann, in which the unit is the amount that the earth would receive in one day at the time of the equinox, if the sun were at its mean distance from the earth: (See page 39.)

From this it appears that the equator receives nearly 2.5 times as much heat yearly as the poles. Since moreover, the equator enjoys nearly constant insolation, while the polar regions suffer great variations of heat, with the varying altitude of the sun, the equatorial atmosphere is both much hotter and more equable than the poles, and high latitudes generally. Thus at the equator the frost level stands constantly at 18,000 feet, while in the middle latitudes it varies greatly in height from season to season. If, for example,

¹Solar radiation received by the earth.

TABLE V
Annual Amounts of Insolation

Latitude	Thermal Days	Difference	Latitude	Thermal Days	Difference
0°	350.3		50°	239.6	19.1
5°	349.1	1.2	55°	219.4	20.2
10°	345.5	3.6	60°	199.2	20.2
15°	339.4	6.1	65°	180.2	19.0
20°	331.2	8.2	70°	166.2	14.0
25°	320.5	10.7	75°	156.5	9.7
30°	307.9	12.6	80°	150.2	6.3
35°	293.2	14.7	85°	146.5	3.7
40°	276.8	16.4	90°	145.4	1.1
45°	258.7	18.1			

a circle be drawn to represent the earth, and above it a line to indicate the mean altitude of the frost level in July, the frost line starting at the equator at an elevation of 18,000 feet will decline north and south, finally touching the earth well toward the frigid zones. The levels for other temperatures, above and below freezing, are similarly inclined downward from the equator to north and south. Obviously these isothermal levels vary with the varying season, and at any fixed time differ on different longitudes. On the plane of any given latitude the frost line varies much less in altitude, and so for the other isothermals. This is particularly true at the poles and equator, and everywhere at considerable altitude. If one voyaged around the earth at the equator at an elevation of 5,000 feet, he should find the average temperature about 65° F. In the temperate zone, following a line of latitude at the same height, he should have a lower temperature, but still comparatively equable. The average annual temperature of the earth's entire surface is about 60° F.

In practical meteorology the temperature is observed at many points simultaneously over a wide stretch of the earth's surface. These are then plotted on a weather chart, and through all points of like temperature are drawn lines known as isothermals. These lines not only map the earth's surface into regions of equal temperature, but they also show the direction of fall or rise of temperature, and its space rate of change. This rate is called the "temperature gradient," and when estimated straight across from isothermal to isothermal, that is in the direction of liveliest change of temperature, it is the maximum gradient. Such a map is very useful in forecasting the weather. It is but a particular instance of the more general map conceived by the physicist, exhibiting the thermal condition of the entire atmosphere by means of a series of equal temperature surfaces one above the other. Here, of course, the temperature gradient at any point is the space rate of change of temperature in any direction, being zero along the isothermal surface and greatest normal to it.

The vertical temperature gradient is of particular interest, since it determines the condition of fluid equilibrium at any point in the atmosphere when the level surfaces are isothermal. If, for example, a balanced balloon or portion of air, on starting upward from any level, cools faster than the environing stagnant air, it will become more dense, and cease to ascend, in which case the atmospheric equilibrium is stable.

If a balloon descends at such a speed that there is no loss or gain of heat the gas is said to contract adiabatically, and to increase in temperature at the rate of 5.4 degrees F. per thousand foot decrease in altitude. Hence in order that these conditions be *stable* it is necessary that the temperature gradient of the air be less than 5.4 degrees for each 1000 foot change in altitude. Again, if the descending gas or air heats more slowly than the surrounding medium, it will become less dense and so continue to descend with increasing velocity, in which case the atmospheric equilibrium is *unstable*, or considering the gas under adiabatic conditions the atmospheric temperature gradient must be greater than 5.4 degrees F. for each thousand foot increase in altitude. Thirdly, if the atmospheric temperature gradient is 5.4 degrees F. the rate of cooling of the gas will be identical with the atmospheric temperature gradient as the gas expands adiabatically, viz., 5.4 degrees F. per thousand foot increase in altitude, and naturally there could be no interchange of temperature as the temperatures of the gas and air are the same, and continue to be the same with an increase in altitude. This condition of equilibrium is *neutral* and the motion will be stopped by friction but unaffected by change of buoyancy since no such change can occur.

Of these three states the stable alone is usually found at altitudes above 5,000 ft. for the reason that the air at this height is not affected to any great extent by the changes in the earth's temperature. Below 5,000 ft., however, any of the three states may occur, the stable occurring nearer the earth when the earth is cooler than the air, and the unstable nearer the earth when the earth is warmer. The neutral state occurs at the change from stable to unstable, or vice versa. During the day the earth becomes very warm due to absorption of the sun's rays, this warm earth heats up the strati of air adjacent to it, causing a large temperature gradient at low altitudes. If this gradient is more than 5.4 degrees for each 1000 foot change in altitude, the atmospheric conditions will be unstable as aforesaid, as is the case late in the morning and in the afternoon.

In winter the temperature gradient is less than in the summer as the earth does not absorb as much heat in the winter as during the summer—also because snow and ice reflect heat rather than absorb it so that less heat is available to heat up the air, hence stable conditions are found oftener during the day in winter than in summer. It may be said, however, that it is not unusual to encounter stable strati at any altitude even on the most unstable days of summer due perhaps to air currents, clouds, etc. Air over snow, ice and water is always more stable than over land as they do not absorb nearly as much heat from the sun as does the earth, and hence can not radiate as much or cause as great a temperature gradient.

Now let us consider the conditions at night. During the day the earth easily absorbs the heat; when the sun has set the heat leaves the earth just as easily. Soon the earth becomes cooler than the air and the atmosphere instead of having a large temperature gradient and being unstable as during the day, is very stable especially near the earth. This is caused by the small temperature change, which sometimes becomes an inversion of the temperature gradient (see Fig. 20), so that the temperature at night often even increases with the altitude for some distance before it begins to decrease.

On a cloudy day the sun can not strike the earth, hence the earth cannot receive much heat and as a result the air is usually more stable. Also above the clouds, stable conditions invariably prevail due to the fact that the clouds being made up of moisture do not rapidly absorb or radiate heat.

Many observations have been made to determine the variation of temperature along the vertical in various places and in different seasons. From the temperature records obtained in 722 balloon ascensions near Paris, France, the mean fall of temperature per 1000 feet up to 20,000 feet was found to be $2^{\circ}.4$ in winter, $2^{\circ}.8$ in spring, $2^{\circ}.6$ in summer, $2^{\circ}.5$ in autumn and $2^{\circ}.6$ for the year. Near Berlin $3^{\circ}.1$ for the year was found from 75 balloon ascensions, the rate being nearly the same for the halves of the year. Fig. 19 gives the average of 52 winter and 65 summer temperature gradients, taken at about 8 A. M. by means of sounding balloons sent up at Munich, Strassburg, Trappe and Uccle. It will be noted that in both summer and winter the temperature falls rapidly with increase of elevation, up to ten or eleven kilometers, but above twelve remains nearly constant for all altitudes. The difference in temperature summer and winter is interesting, also in its gradual diminution with altitude. Another striking feature is the inversion of gradient shown at twelve kilometers elevation, where the temperature ceases to diminish, and may even increase with altitude. This region is known as the upper inversion level of the atmosphere, as distinguished from other levels at or below three kilometers height, known as lower inversions, where the temperature gradient is sometimes reversed, though not so illustrated in the diagram.

The above figures give the average gradient up to 20,000 feet. Balloons, however, usually fly at a height less than 5,000 feet, hence an average of the temperature gradient below this altitude will be of more advantage than that given above. From a long series of observations taken at Blue Hill observatory it was found that a daily average of the temperature winter and summer for a year was about 2 degrees F. per thousand feet at both 9 A. M. and 8 P. M. This average is less than that given in the preceding data but by consulting Fig. 19 it can be seen that the curve shows a lesser gradient at low altitudes. Fig. 20 gives the results of the Blue Hill observations. The dotted lines, lines labeled day and night, show the diversion from the standard curve during day and night. This curve shows clearly how the atmosphere becomes stable or unstable and shows the temperature inversion at night very well. The curve of neutral atmosphere shown on this chart can also be taken as the curve of adiabatic expansion of a gas, viz., 5.4° per thousand feet change in altitude. Hence any curve whose tangent is steeper than this curve represents stable conditions, while the curves which are flatter indicate an unstable state. This curve of average temperature must be used carefully and with reason if used at all for any calculations. The average temperature at any other time of day than at 9 A. M. and 8 P. M. will give a different curve, the curves of winter and summer will be different, the curve of a sunny day will be different from a cloudy day. However, this curve gives a good idea of the general change of the temperature with height and is a curve of actual observations.

Thus the atmosphere divides into three marked layers. The lower layer, three kilometers deep, is the region of turbulence and storm, the home of heavy rain clouds, lightning, wind gusts and irregular temperatures. The middle layer, some seven kilometers thick, bounded top and bottom by the upper and lower inversion levels, is a clear region of steady-falling temperature, for the most part frigid—a region of far reaching and rapid winds, sweeping eastwardly, except near the equator, and bearing on their backs the frosty cirrus clouds. The upper layer reaching from the cirri to the cosmic void, is always cloudless and very frigid, with temperature nearly constant, or maybe slightly increasing with elevation.

A striking peculiarity of these three regions is that the lower and middle layers may freely intermingle with each other, but never with the upper, or isothermal layer. Owing to its constant temperature, the upper layer floats on its neighbor like oil on water.—W. J. Humphreys, *Astro. Phys. Journ.*, January, 1909. If a mass of dry air were forced up into it from below, with the natural cooling due to adiabatic expansion, such mass would be denser than the surrounding medium, and hence would promptly sink back to its initial position. Thus whatever turmoil may vex the middle or lower region, it can at most upheave the floor of the isothermal layer, leaving inviolate the crystal depths of the empyrean.

We may now turn to the distribution of barometric pressure in the atmosphere and the effect of its variation. In general, the distribution is not very uniform, but it can be graphically pictured by drawing a series of surfaces connecting all points of equal pressure. These are called isobaric surfaces. In a stagnant uniformly heated atmosphere, for example, these surfaces would lie one above the other parallel to the ocean face; but where turmoil exists, and irregular temperature distribution, the isobaric surfaces are bent into hills and hollows of varied form. These surfaces not only map the aerial sea into regions of equal pressure, but they also show the direction of fall or rise of pressure, and its space rate of change. This rate is called the "pressure gradient." When estimated straight across from surface to surface, that is, in the direction of the liveliest change of pressure, it is the maximum pressure gradient. Along this normal direction the air tends to flow with an acceleration proportional to the gradient. The velocity thus acquired by any portion of air in being pushed along the line of falling pressure, combined with its velocity due to other causes, gives its true velocity. A most important consideration, therefore, in a scientific study of the wind is the pressure distribution.

In practical meteorology, observations of the barometric pressure are made simultaneously at many points on the earth's surface, and the readings then plotted on a map, after "reduction to sea level." This reduction is made by adding to each barometric reading the weight of a column of air between the barometer level and the sea level, according to tables prepared for this purpose. Lines called "isobars" (an isobar is a line of intersection of an isobaric surface with a water level surface at any altitude) are then drawn, at regular intervals, through all points of like sea-level pressure, the indicated change of pressure between consecutive isobars on the U. S. weather map being usually one-tenth of an inch of mercury. These exhibit at once, over the entire field of observation, the horizontal pressure gradient reduced to sea level, and commonly called the "barometric gradient." In meteorology, the pressure normal to the isobar is called the gradient, and is expressed in millimeters of mercury per degree of a great circle. On the same weather chart are mapped the isothermal lines and wind directions for all the stations of the weather service. From these data and the reported moisture conditions, the meteorologist forecasts the probable weather some hours or days in advance.

No perfectly comprehensive formula can be given for the barometric pressure at any place and altitude, but certain general laws may be observed. Where, for example, the speed of the air is increased along any level of an air stream, the pressure is lessened, and conversely. Thus, if the wind blows squarely against the front of an isolated house, the speed will be greatly checked at the center front, and accelerated at both sides and over the roof, thereby increasing the apparent barometric pressure on the front, and lessening it on the sides and over the top. A similar effect may be observed when the air flows round the hull and framing of air craft.

Below are given several formulæ for determining the altitude from barometric pressure readings:

Approx. formulæ $D = 55000 \left(\frac{H-h}{H+h} \right)$

More accurate formulæ $D = (H-h) \left(1 + \frac{T+t-100}{1000} \right)$

Where

D = Difference in altitude in ft.

H = Baro pressure at start in inches of Mercury.

h = Baro pressure at the altitude in inches of Mercury.

T = Temperature at start in degrees F.

t = Temperature at altitude in degrees F.

For rough calculations a decrease of 1 inch of mercury for each 1000 feet increase in altitude can be used with fair accuracy up to 6000 or 7000 ft. On the chart shown in Fig. 20 will be seen the approx. pressure at various altitudes.

Again, if the atmosphere over any locality is heated appreciably more than its environment, the heated column tends to expand upward and overflow aloft in all directions toward the cooler neighborhood, thus lessening the pressure throughout the heated column, and increasing the pressure throughout the environing atmosphere laterally. When this effect is marked the plotted isobars often form a series of closed curves about the heated region, manifesting a pressure gradient at the lower levels in all directions toward the heated area. This grouping of the isobars exhibits the familiar low pressure area of the weather map. On the other hand, if any locality be cooled appreciably more than its environment, the cooled column sinks, so that the surrounding warmer air aloft flows in over it, thereby increasing the pressure over the cooled area, and diminishing it throughout the environment. The isobars may then form a series of closed curves about the cooled region, with a pressure gradient along the higher levels in all directions away from the cooled area. Of course, if heat were the only agency disturbing the earth's barometric pressure, there should be a parallelism between the heat and pressure gradients; but, as already noted, the speed or momentum of the aerial currents is also a substantial agency in modifying the pressure lines.

It is well to remember that, while the base of a warm column of air may, due to the overflow aloft, have less pressure than the base of the cool environing column which receives the overflow, the high part of the column may have greater pressure than the equally high part of the cool. For if the columns be initially of the same temperature and pressure, heating one of them uplifts its levels of giving pressure above those of its neighbor. When the overflow begins, a partial equalization of pressure levels occurs, but not a complete one so long as the flow has any head.

An interesting hygrometric feature of these highs and lows may here be observed in passing. As already explained, when a column of air ascends it cools by expansion, and tends to precipitate its water content as cloud or rain; and conversely, when the air sinks it heats by compression, thus acquiring greater moisture capacity and tending to clarify. As a consequence, the areas of low pressure and a rising atmosphere are usually marked by clouds and rainfall, while the areas of high pressure and falling atmosphere are marked by clear, or clearing weather. In the low, damp areas, then, the air feels heavy while it is really light; in the high and dry area the air feels light, while it is really dense, and most favorable to air men for carrying heavy loads in their balloons or flyers. Similarly when air flows over a mountain range the ascending stream precipitates moisture, due to cooling by expansion, while the descending stream, on the other side, comes down hot and dry, due to compression.

A characteristic mechanical feature of the high and low pressure areas is the closed circulation between them, involving practically the whole atmosphere below the isothermal layer. If we conceive the entire globe spotted with high and low areas, we may picture the air surging upward in the lows, flowing outward under the isothermal layer, descending in the highs, then flowing outward along the earth's surface toward the lows in a continuous cycle. Thus, chiefly is maintained the vast and multifold circulation of the atmosphere over the entire world.

In general the motion is of a vortical nature, by which is meant that the masses of air as they flow along stream suffer more or less change of orientation in space, the rotation at times being so slight as to be undetectable, and again so marked as to excite wonder, as in the whirlwind. Many of these atmospheric vortices, even though varying in diameter from a few yards to hundreds of miles, resemble in their behavior the gyrating column of water in a common circular basin emptying through an orifice at its bottom. If the water is very still when the drain opens, the column descends with imperceptible, if any, rotation; but if the column has an initial whirl, or angular velocity, this is magnified as the water approaches the axis of the vortex, the tendency of the mass being to preserve its angular momentum, or fly wheel property. A like action obtains in the great atmospheric vortices, though here the motion far from the axis may seem like a straight-blowing wind, rather than part of a vast whirl covering thousands of square miles.

But even if all the air started directly for the axis of the ascending column, like still water in a basin, it would promptly acquire vortex motion, because it flows on the surface of a rotating sphere. The deflection so produced is evidently greatest at the poles, and for other places equals the polar value multiplied by the sine of the latitude. The effect is similar to what occurs when a basin, rotating about a vertical axis and carrying water with the same angular velocity, is opened at the bottom. In this case the water at once begins to gyrate within the basin, as the particles move toward its axis.

As previously explained the earth absorbs and radiates heat more rapidly than the water, hence the air

over the earth becomes warmer than over the water during the day, and warmer over the water at night. Now as warm air is less dense than cool air, the air over the land at the coast tends to rise during the day, while that over the water descends and flows over the land to replace the air that has arisen to higher altitudes. This gives the characteristic sea breeze during the day. However, as the sun sets, the earth becomes rapidly cooler and the breeze at night takes the reverse direction and blows from land to sea. This same action takes place over a large lake causing a vertical current of air over it. Over small lakes, however, the effect is seldom felt.

Another air current that should be considered briefly is that of a wind blowing over a hill. The wind will invariably follow the contour of the land, smoothing off sharp "bumps"; in other words, it shoots over small deep pockets and steep cliffs, following the contour of the earth only approximately. This fact is very convenient in ballooning for a balloon sailing along at constant altitude would appear to strike a hill but instead would be carried over it and returned to the same altitude on the other side with no loss of gas or ballast.

Chapter V

Theory of Ballooning

As previously explained a balloon rises not because of any lifting power of the gas within it, but because the weight of a volume of air is greater than the weight of an equal volume of gas. Archimedes' principle states that a body immersed in the fluid is buoyed up by the weight of the fluid displaced. According to this law a vacuum would have a greater lifting power than the same volume of any gas whatsoever, for the lightest gas has some weight. Hence in order to find the lifting power of any volume of gas, it is only necessary to have the volume of the gas, the average density of the gas and the average density of the air displaced; for example, it is desired to know the lifting power of 10,000 cubic feet of hydrogen at sea level.

Let us take the following constants (30" Mercury and 70° F. being considered average sea level conditions or conditions of zero altitude).

Weight of 1 cu. ft. of air at 30" pressure and 70° F.075 pounds
Weight of 1 cu. ft. of (hydrogen) H at 30" pressure and 70° F.005 "

from formula (11) Chapter 2.

$$\begin{aligned}
 10000 \times .075 &= 750 \text{ lbs. buoyancy of air at sea level.} \\
 10000 \times .005 &= \frac{50}{700} \text{ lbs. weight of H at sea level.} \\
 &\quad \text{700 lbs. lift at sea level.}
 \end{aligned}$$

This quantity 700 lbs. represents the total weight that this gas could lift. If we assume 300 lbs. as the total weight of bag and basket we have a net lift of $700 - 300 = 400$ which represents the weight of passengers and ballast to preserve equilibrium.

Comparison of Natural Gas and Hydrogen. Now let us consider the balloon filled with natural gas instead of hydrogen.

Average weight of 1 cu. ft. of natural gas at 30" pressure and 70° F. = .049 lbs.

$$\begin{aligned}
 10000 \times .075 &= 750 \text{ lbs. buoyancy at sea level.} \\
 10000 \times .049 &= 490 \text{ lbs. weight of gas at sea level.} \\
 &\quad 260 \text{ lbs. lift at sea level.}
 \end{aligned}$$

The total weight of the balloon as given above was 300 lbs. while the lift is only 260 lbs., hence this bag when inflated with natural gas would not lift itself off the ground, while the same balloon filled with hydrogen would carry a load of 400 lbs.

Effect of Temperature. In order to determine the effect of temperature on the lift of a balloon let us now consider the 6 following conditions in each case a 10,000 cu. ft. balloon filled with hydrogen is considered in equilibrium at the sea level (30" 70° F.) at start and no change is made in altitude.

First, if atmospheric temperature changes from 70° F. to 100° F. (a 30 degree increase) with no change in gas temperature.

In this case as the gas does not change in temperature or pressure there is no change in volume or weight, hence the only change in lift is due to change in buoyancy.

From formula (10) chapter 2:

$$\begin{aligned}
 d(\text{air}) &= d_0 \frac{P T_0}{P_0 T} = .075 \frac{30(460.6 + 70)}{30(460.6 + 100)} = .0708 \\
 10,000 \times .0708 &= 708 \text{ lbs. buoyancy of air at } 30'' - 100''. \\
 10,000 \times .005 &= \frac{50}{658} \text{ lbs. Weight of H at } 30'' - 70'' \\
 &\quad \text{658 lbs. lift} \\
 658 - 700 &= -42 \text{ lbs. decrease in lift.}
 \end{aligned}$$

Second, if gas temperature changes from 70° F. to 100° F. (a 30 degree increase) with no change in atmospheric temperature.

In this case the gas increases in temperature and expands and a portion of it is lost as the balloon will only hold 10,000 cu. ft. This loss of gas is just so much loss of weight and as the volume of the balloon

(not the gas as some is lost) remains the same the buoyancy remains the same; hence the only change in lift is due to change in weight of gas. From formula (10):

$$d(\text{gas}) = .005 \frac{30(460.6 + 70)}{30(460.6 + 100)} = .0047$$

$$10,000 \times .075 = 750 \text{ lbs. buoyancy of air } 30^\circ - 70^\circ \text{ F.}$$

$$10,000 \times .0047 = \frac{47 \text{ lbs. Weight of H } 30^\circ - 100^\circ \text{ F.}}{703 \text{ lbs. lift.}}$$

$$703 - 700 = +3 \text{ lbs. increase in lift.}$$

Third. If both gas and air change from 70° F. to 100° F. (a 30° F. increase). This case is a combination of cases 1 and 2.

$$10,000 \times .0708 = 708 \text{ lbs. buoyancy of air } 30^\circ - 100^\circ \text{ F.}$$

$$10,000 \times .0047 = \frac{47 \text{ lbs. weight of H } 30^\circ - 100^\circ \text{ F.}}{661 \text{ lbs. lift.}}$$

$$661 - 700 = -39 \text{ lbs. decrease in lift.}$$

Fourth. If atmospheric temperature changes from 70° F. to 40° F. (a decrease of 30° F.) with no change in gas temperature.

In this case as in case 1 the only change is in the buoyancy of the atmosphere. From formula (10):

$$d(\text{air}) = .075 \frac{30(460.6 + 70)}{30(460.6 + 40)} = .0792$$

$$10,000 \times .0792 = 792 \text{ lbs. buoyancy of air } 30^\circ - 40^\circ \text{ F.}$$

$$10,000 \times .005 = \frac{50 \text{ lbs. weight of H } 30^\circ - 70^\circ \text{ F.}}{742 \text{ lbs. lift.}}$$

$$742 - 700 = +42 \text{ lbs. increase in lift.}$$

Fifth. If gas in balloon changes from 70° F. to 40° F. (a decrease of 30° F.) with no change in atmospheric temperature.

This case is decidedly different from any of the others for when the gas decreases in temperature it contracts in volume giving a lesser volume of displaced air or buoyancy though the density of the air is the same. This is the first case in which the volume of gas in the balloon has been affected. Also contrary to case 2 the weight of gas does not change as the gas contracts and none is lost.

From formula (7) we have:

$$V = V_0 \frac{P_0 T}{P T_0} = 10,000 \frac{30(460.6 + 40)}{30(460.6 + 70)} = 9,440$$

From formula (10):

$$d(\text{gas}) = .005 \frac{30(460.6 + 70)}{30(460.6 + 40)} = .0053$$

$$9440 \times .075 = 708 \text{ lbs. buoyancy of air at } 30^\circ - 70^\circ \text{ F.}$$

$$9440 \times .0053 = \frac{50 \text{ lbs. Weight of H at } 30^\circ - 40^\circ \text{ F.}}{658 \text{ lbs. lift.}}$$

$$658 - 700 = -42 \text{ lbs. decrease in lift.}$$

Attention is drawn to the weight of H which is the same as before the temperature decreased. When the temperature fell the volume naturally decreased, but at the same time the density increased. The volume decreased in the ratio of $\frac{500.6}{530.6}$ while the density increased by the ratio $\frac{530.6}{500.6}$

$$\text{Hence } \left(V \times \frac{500.6}{530.6}\right) \times \left(d \times \frac{530.6}{500.6}\right) = Vd \text{ showing no change in weight.}$$

It would not have been necessary to have considered the weight of H at all if it were known that no gas was lost or taken into the balloon, and the difference in buoyancy could be considered the difference in lift, even though it were the gas temperature that was changed, and not the air temperature. The reason for this is that change of lift is affected only by weight of gas and weight of air displaced. If gas weight

doesn't change, the air weight or buoyancy only can affect the lift. Now buoyancy is affected by volume and density as it is the product of the number of cubic feet multiplied by the weight of 1 cubic foot or density.

Below is given the shorter method of calculating change in lift when gas weight does not change:

$$\begin{aligned} 10,000 \times .075 &= 750 \text{ buoy. at } 30^\circ - 70^\circ \\ 9440 \times .075 &= 708 \text{ buoy. at } 30^\circ - 40^\circ \\ &\quad - 42 \text{ change in lift same as before.} \end{aligned}$$

Sixth, or last case is still different, and possibly will be a little surprise.

It is the condition when both gas and air decrease from 70° F. to 40° F.

As explained in the preceding case it is unnecessary to consider the weight of gas, as it contracts with decrease in temperature and none is lost, so we will consider change in buoyancy as being the change in lift.

The volume of gas or air displaced at 40° from case 5 is 9440 cu. ft. and the density of the air from case 4 is .0795. Now weight is volume multiplied by density.

$$\begin{aligned} 9440 \times .0795 &= 750 \text{ lbs. buoyancy after change.} \\ 10,000 \times .075 &= 750 \text{ lbs. buoyancy before change.} \\ &\quad 0 \text{ change in lift.} \end{aligned}$$

In other words if both gas and air decrease in temperature at the same rate there is no change in lift. Let us now compare these 6 results and draw conclusions.

Case 1	air increases 30°	gas increases 0°	lift decreases 42 lbs.
" 2 "	" " 0°	" " 30°	" increases 3 "
" 3 "	" " 30°	" " 30°	" decreases 39 "
" 4 "	decreases 30°	decreases 0°	" increases 42 "
" 5 "	" " 0°	" " 30°	" decreases 42 "
" 6 "	" " 30°	" " 30°	" no change

These six cases are all considered with the balloon completely filled with gas at start; if, however, the balloon is only partially full, the second and third cases will be affected. The gas will increase in volume without loss of weight until the balloon is full, then the conditions will be the same as in preceding conditions. As before stated, if there is no loss of gas, change of buoyancy can be considered change of lift, hence as the volume of gas increases, due to increased temperature, the buoyancy will increase and this increase will be much larger than when the balloon is full. In fact the increase in buoyancy due to increase in gas temperature exactly neutralizes the decrease in buoyancy due to decrease in density, similar to case 6. If the temperature change is the same for both so that when the gas and air increase in temperature at the same rate and no gas is lost there is no change in lift as follows:

Consider the same 10,000 cubic foot balloon but only $\frac{3}{4}$ full of H at 30° and 70° F.

Temperature of both gas and air increases to 100° F. What is change in lift?

$$\text{From (7):} \quad V = 7500 \frac{30 (460.6 + 100)}{30 (460.6 + 70)} = 7930 \text{ cu. ft.}$$

$$\text{From (10):} \quad d (\text{air}) = .075 \frac{30 (460.6 + 70)}{30 (460.6 + 100)} = .071.$$

$$7500 \times .075 = 563 \text{ lbs. buoyancy } 30^\circ - 70^\circ \text{ F.}$$

$$7930 \times .071 = 563 \text{ lbs. buoyancy } 30^\circ 100^\circ \text{ F.}$$

$$0 \text{ change of lift.}$$

Conclusions that can be drawn from changes in temperature:

- (1) When atmospheric temperature increases the buoyancy decreases, and vice versa.
- (2) When gas temperature increases if balloon is full there is always a loss of gas or weight.
- (3) When gas temperature decreases there is no loss in weight but loss in volume, hence loss in buoyancy.
- (4) When both gas and air increase in temperature, balloon being full, the loss of gas tends to increase the lift, while the air density tends to decrease the lift, the effect of the air being many times greater than the gas.
- (5) When both gas and air decrease in temperature one effect tends to neutralize the other and if the temperature decrease is the same for both there is no change in lift.

Effect of Change in Altitude. All the problems considered thus far have been taken at a constant altitude or barometric pressure. At any other altitude the density of both gas and air is different from that at the sea level or zero altitude. The density at any altitude can be determined as shown in Chapter II by formula (10).

Balloon Full of Gas. Let us calculate the change in lift of a 10,000 cu. ft. balloon full of hydrogen rising from the sea level to 5,000 ft. altitude.

As aforesaid the barometric pressure decreases at the rate of approximately 1" of mercury for each 1,000 ft. increase in altitude up to 6,000 or 7,000 ft. therefore the baro. pressure would be approximately $30'' - 5'' = 25''$. To be more exact see chart in Fig. 20 which gives 24.9" as the pressure at 5,000 ft.

The temperature of the gas, assuming no radiation from the sun and no change from adiabatic effect, would be the same as the air which will vary according to the time of day. In this problem let us consider the time 9 A. M. and take the temperature from the chart in Fig. 20 as 60 degrees F. this is a decrease of 10° F. which corresponds exactly to the approximate rule of 2° F. for each 1000 change in altitude up to 6000 or 7000 ft.

Now having the pressure and temperature at 5000 foot altitude respectively 25" and 60° F. we may at once determine the density of gas and air at 5000 feet by formula (10).

$$d = d_0 \frac{P T_0}{P_0 T} = .075 \frac{25 (460.6 + 70)}{30 (460.6 + 60)} = .0638 \text{ for air at } 25'' - 60^\circ \text{ F.}$$

$$d = .005 \frac{25 (460.6 + 70)}{30 (460.6 + 60)} = .0043 \text{ for gas at } 25'' - 60^\circ \text{ F.}$$

Investigating these equations it will be seen that the effect of temperature change is very small compared with the effect of pressure change at the two elevations. Fortunately, this is true, for the pressure at various altitudes can be determined much more accurately than the temperature. In this problem the change in lift rising from zero altitude to 5,000 ft. due to pressure is in the ratio of 25 to 30 while that due to temperature is in the ratio of 530.6 to 520.6. In other words the pressure effect is over ten times that of the temperature.

When a balloon rises the gas expands because the decrease in pressure causes the volume to increase more rapidly than the opposite affect of the temperature as just explained. Now as the balloon under consideration will hold just 10,000 cu. ft. a certain amount of gas is lost but the volume is the same in each case. Therefore:

$$10,000 \times .075 = 750 \text{ lbs. buoyancy of air } 30'' - 70^\circ$$

$$10,000 \times .005 = \frac{50 \text{ lbs. weight of H}}{700 \text{ lbs. lift at } 30'' - 70^\circ}$$

$$10,000 \times .0638 = 638 \text{ lbs. buoyancy of air } 25'' - 60^\circ$$

$$10,000 \times .0043 = \frac{43 \text{ lbs. weight of H}}{595 \text{ lbs. lift at } 25'' - 60^\circ}$$

$$700 - 595 = 105 \text{ lbs. decrease lift.}$$

This means that to start from the sea level with a balloon completely full of H it would be necessary to throw over 105 lbs. of ballast to rise to an altitude of 5000 ft. Remember, this is considering the balloon full of gas.

Balloon Partially Filled With Gas. Let us now consider this same 10,000 cubic foot balloon at sea level just balanced as before but only $\frac{3}{4}$ filled with H. How much ballast will now have to be released to attain the 5000 ft. altitude?

$$10,000 \times \frac{3}{4} = 7500 \text{ volume at zero altitude.}$$

$$\text{From (7). } V = 7500 \frac{30 (460.6 + 60)}{25 (460.6 + 70)} = 8830 \text{ volume at 5000 ft.}$$

$$\text{as before density of air at 5000 ft.} = .0638$$

$$\text{and " " gas " " " " } = .0043$$

$$\text{Then } 7500 \times .075 = 563 \text{ lbs. buoyancy at sea level.}$$

$$7500 \times .005 = \frac{37.5 \text{ gas weight at sea level.}}{525.5 \text{ lift at sea level.}}$$

$$8830 \times .0638 = 563 \text{ lbs. buoyancy at 5000 ft.}$$

$$8830 \times .0043 = \frac{37.5}{525.5} \text{ gas weight at 5000 ft.}$$

$$525.5 \text{ lift at 5000 ft.}$$

If a balloon is only partially full of H and the temperature of the gas remains the same as the atmosphere it will be in equilibrium at any altitude up to that at which it is completely filled with gas, in other words this balloon upon releasing a fraction of a pound would rise until it was completely filled and at that altitude if a very small quantity of gas were released the balloon would gradually sink to the earth.

Of course as a balloon floats about in the atmosphere it will occasionally strike a vertical current, or a cool current which will affect its stability, the condition given above is an ideal condition. It was stated before that pressure affected buoyancy ten times as much as temperature, and so it does, but when a balloon is only partially full and in equilibrium, a slight change of temperature of either gas or air may make a great change in altitude without affecting the lift at all, considering that this slight increase in temperature of either gas or air continues to hold.

The vertical current may be caused by the air being warmer or cooler than the surrounding air as for instance in the case of the warm current of air rising out of a chimney. When a balloon encounters such a current there are two forces on the balloon. One is the upward force of the current and the other is the downward force due to the change in density of the atmosphere. Invariably the force due to change in density is the greatest, and when the balloon encounters the warm upward current of air, it descends instead of rises as would be expected, due to the decrease in buoyancy.

Adiabatic Effect. As explained in Chapt. II hydrogen will decrease in temperature at the rate of 5.4° F. per 1000 ft. increase in altitude if left free to expand in a balloon. This decrease would always take place if the gas did not absorb heat from the air and become warmer, or vice versa. The gradient of the air or change of atmospheric temperature per thousand feet may be most anything. If it is 5.4° F. the atmosphere is said to be neutral, and a balloon partially filled with gas will be in stable equilibrium at any height up to the height at which it is completely filled, chart in figure 20 gives a curve of neutral atmosphere.

Stable and Unstable Conditions. If the decrease in temperature of the atmosphere is greater than 5.4° F. for each 1000 ft. rise, the atmosphere is unstable and a balloon cannot be kept at one altitude without continually discharging gas or ballast. The condition can be likened to a body of the same specific gravity as water immersed in water. It will either rise to the surface or sink to the bottom, it will not be stable elsewhere. If a balloon be allowed to descend while in unstable atmosphere its velocity accelerates until it requires a very large amount of ballast to stop it, because as the balloon descends the temperature gradient of the gas is 5.4° (adiabatic) while the atmospheric gradient is greater forming a lighter, less dense air which has less buoyancy and will not support the balloon, the buoyancy decreasing more and more as the balloon descends.

In stable air the reverse takes place as the atmospheric gradient is less than 5.4° . At lower altitudes the buoyancy increases instead of decreases as in the preceding case. The reason for this is because the density of the air increases more rapidly than the density of the gas. The effect is that a balloon in stable atmosphere will sometimes ride for hours at the same altitude without any change in equilibrium for as soon as it drops slightly the denser air tends to raise it up again.

Another factor that greatly affects the stability of a balloon and which also causes the instability of the atmosphere is radiation, this is described in detail in Chapter II.

Lift When Gas and Air are of Different Temperatures. If from general conditions of the sun, atmosphere, time of day, observation, etc., it is possible to approximately estimate the temperature of the atmosphere at various altitudes, it will be possible to estimate how high a certain amount of ballast will carry a balloon, or how much ballast must be discharged to cause the balloon to rise to a certain height. A small error in the temperature will not greatly affect the result for as aforesaid the temperature has but one-tenth the effect that the pressure has. The speed at which the balloon rises will have a great effect on the gas temperature, however, for if the balloon ascends at such a speed that the transfer of heat between the balloon and the air is negligible the temperature of the gas can easily be calculated for any height by reducing the starting temperature by 5.4° F. for each 1000 foot increase in altitude. If, however, the ascent is slow the gas assumes the air temperature which can be estimated.

Let us consider a 10,000 cu. ft. balloon full of H and in equilibrium at the 1000 ft. altitude consider

average atmospheric conditions at 9 A. M. as given on chart in Fig. 20, how much ballast will have to be discharged to rise to an altitude of 5000 ft., considering a rapid rise.

As we start at 1000 ft. altitude in this problem it is necessary first to find the lift at 1000 ft. altitude.

$$10,000 \times .075 \frac{29 (460.6 + 70)}{30 (460.6 + 68)} = 727 \text{ lbs. buoyancy at 1000 ft.}$$

$$10,000 \times .005 \frac{29 (460.6 + 70)}{30 (460.6 + 68)} = \frac{48.5 \text{ lbs. gas weight at 1000 ft.}}{678.5 \text{ lbs. lift at 1000 ft.}}$$

At 5000 ft. the volume is the same as at 1000 ft. but the density of air and gas are both less. The temperature of the atmosphere on rising from 1000 ft. to 5000 ft. has decreased 2×4 or 8° F. while the gas decreasing at the rate of 5.4° for each thousand ft. has decreased $4 \times 5.4 = 21.6^\circ \text{ F.}$ making the gas temperature $68 - 21.6 = 46.4^\circ \text{ F.}$

$$10,000 \times .075 \frac{25 (460.6 + 70)}{30 (460.6 + 60)} = 638 \text{ lbs. buoyancy at 5000 ft.}$$

$$10,000 \times .005 \frac{25 (460.6 + 70)}{30 (460.6 + 46.4)} = \frac{43.6 \text{ lbs. gas weight at 5000 ft.}}{594.4 \text{ lbs. lift at 5000 ft.}}$$

$678.5 - 594.4 = 84.1$ lbs. of ballast must be discharged rapidly to attain a height of 5000 ft. If this ballast is discharged slowly the gas takes the same temperature as the air so that the only change in the solution is to substitute 60 for 46.4 in the last equation and solve as before. The resultant amount of ballast to be discharged slowly is found to be slightly less than when discharged rapidly.

Should it be required to learn how high this same balloon would rise if 100 lbs. were suddenly discharged we proceed as follows:

The first step would be the same as before giving a lift of 678.5 lbs. at 1000 ft.

At altitude Y the lift = $678.5 - 100 = 578.5$ lbs. Let P_Y , T_A , and T_G be pressure, and gas and air temperature respectively at altitude Y.

$$(a) \quad 10,000 \times .075 \frac{P_Y (460.6 + 70)}{30 (460.6 + T_A)} = \frac{13300 P_Y}{460.6 + T_A} \text{ Buoyancy at altitude Y.}$$

$$(b) \quad 10,000 \times .005 \frac{P_Y (460.6 + 70)}{30 (460.6 + T_G)} = \frac{884 P_Y}{460.6 + T_G} \text{ Weight of gas at altitude Y.}$$

$$(a) - (b) = \text{lift.}$$

$$\frac{13300 P_Y}{460.6 + T_A} - \frac{884 P_Y}{460.6 + T_G} = 578.5$$

Now it is simply necessary to find the altitude that corresponds to the pressure P_Y , air temperature T_A and gas temperature T_G . This may be obtained from curves in Fig. 20 using the cut and try method substituting some value for the pressure, and the corresponding values on the other two curves for T_A and T_G and solving. If the equation reduces to an identity the assumption was correct, and the altitude corresponding to this pressure is the required altitude, if it does not, another assumption must be made.

Another more simple but approximate method is as follows:

If we let Z = the altitude in thousands of feet above the starting point and assume that the baro. pressure decreases $1''$ for each 1000 feet then $29 - Z = P_Y$.

Again if we assume that the air temperature decreases at the rate of 2 degrees for each thousand ft. then $T_A = 68 - 2Z$ and similarly $T_G = 68 - 5.4Z$. (Rapid rise.)

Substituting these values for P_Y , T_A and T_G ,

$$\frac{13300 (29 - Z)}{460.6 + (68 - 2Z)} - \frac{884 (29 - Z)}{460.6 + (68 - 5.4Z)} = 578.5$$

Solving for Z the required altitude is found.

This problem becomes much simpler if the gas and air temperature remain the same for T_A then = T_G .

Impurities in Gas. Impurities in a gas decrease its lifting power by decreasing the volume of pure gas in a given volume, for instance if gas is 95% pure, 95% of the volume is pure gas and 5% is impurities in other words 5% of the lift of the balloon is lost and this must be sacrificed from the ballast, for example a 10,000 cu. ft. balloon full of pure H at sea level has a buoyancy of $10,000 \times .075 = 750$ lbs. its weight is

300 lbs., two passengers weigh 300 lbs., and the weight of the gas is $10,000 \times .005 = 50$ lbs., this leaves a balance of 100 lbs. to be carried as ballast. If the gas is only 90% pure its buoyancy is 675 lbs. leaving a balance of only 25 lbs. for ballast. Hence if the gas contains but 10% of impurities the possible ballast to be carried is cut down from 100 lbs. to 25 lbs. Thus can be seen the importance of pure gas.

Air in Balloon Considered as Weight. Another more accurate method of working these problems and a method greatly used in dirigible work is to deduct from the buoyancy of the *entire* balloon the weights of all the gases in the balloon for example. A 10,000 cu. ft. balloon is $\frac{3}{4}$ full of H 90% pure at the sea level. What is the lift of the gas?

$$10,000 \times .075 = 750 \text{ lbs. buoyancy of entire balloon.}$$

$$10,000 \times \frac{3}{4} = 7500 \text{ volume of impure H.}$$

$$10,000 - 7500 = 2500 \text{ volume of free air.}$$

$$7500 \times .90 = 6750 \text{ volume of pure H.}$$

$$7500 - 6750 = 750 \text{ volume of impurities.}$$

If we consider the weight of impurities at .05 lbs. per cu. ft. we have the following weights to be deducted from the buoyancy in order to give the lift.

$$6750 \times .005 = 33.75 \text{ Weight of gas.}$$

$$2500 \times .075 = 187.50 \text{ Weight of air.}$$

$$750 \times .05 = \underline{37.50} \text{ Weight of impurities.}$$

$$258.75 \text{ Total weight of gases.}$$

$$750 - 258.75 = 491.25 \text{ Lift.}$$

By using this method the lift due to any difference between the temperature of the air in the gas bag and the atmosphere can be considered.

The curves in Fig. 21 furnish a quick method of determining the density of air and gases at various pressures and temperatures. These curves are self explanatory as an inspection will show.

In working any problems of the type illustrated in this Chapter it is good policy to always work with the buoyancy of the air and weight of the gas as a whole taking their difference to get the net lift instead of using the lift of a cubic ft. of gas. Compare the two following methods:

$$10,000 \times .075 = 750 \text{ Buoyancy of air.}$$

$$10,000 \times .005 = \underline{50} \text{ Weight of H.}$$

$$700 \text{ Net lift.}$$

$$\text{Or: } .075 - .005 = .07 \text{ Lift of 1 cu. ft. of H.}$$

$$10,000 \times .07 = 700 \text{ Net lift.}$$

Both of these methods are correct but the first method is considered the better. In the second, there is always danger of neglecting the effect of possible difference in temperature of gas and air, also there is a greater chance of error in calculating the weight of air in the balloon should it have a temperature different from the atmosphere. Considering everything the first method given is the best to follow.

Chapter VI

Instruments Used in Ballooning

Barometer (Aneroid Type). The barometer is an instrument for registering the atmospheric pressure, or the weight of the entire column of air above. As the density of the air changes, the weight of this column also changes. However, the weight of the entire column of air at the sea level one square inch in area is usually found to be about 14.7 pounds, which is equivalent to the weight of a column of mercury 30 inches in height. It is in terms of its equivalent height of mercury that the barometric pressure is usually given. As previously explained, the barometric pressure decreases inversely with the distance from the earth—hence if the barometric pressure corresponding to various heights is known it is possible to ascertain the altitude of a balloon.

As the baro. pressure at the earth varies from time to time, naturally the pressure at a certain height above would not be sufficient to determine its altitude, but the pressure at the earth must also be considered.

The scale of a barometer used for indicating altitudes is usually graduated so that it reads directly in feet or meters. For example, 31 inches of mercury is marked 0 altitude, 30 inches of mercury 1000 feet, 28.9—2000 ft., 27.9—3000 feet., etc. Now if the barometer reads 28.9 at the start and the balloon ascends until the pressure has become 27.9, the balloon has risen 3000—2000 or 1000 ft. If the balloon rises from a pressure of 31 inches to 30 inches, a like height of 1000 feet has been covered.

Some instruments have a movable altitude scale so that zero altitude can be set at the starting pressure making a direct reading instrument. This is not best, however, as the size of the scale divisions vary with the altitude, causing inaccuracies.

Thirty-one is arbitrarily taken as the pressure at zero altitude because the pressure at the sea level seldom exceeds this. Any other pressure could have been used just as well.

As it was found impractical to carry a mercurial barometer in a balloon the aneroid barometer was invented. The aneroid is nothing more than two thin corrugated circular concave disks (Fig. 25), whose edges are securely attached together, leaving a vacuum space between. From this space all of the air has been exhausted causing the centers of the disks to be forced closer together due to the pressure of the atmosphere on the outside. It can be clearly seen that any change in atmospheric pressure will vary the distance between the center of the disks, a decrease in pressure allowing the spring of the corrugated metal to separate the centers slightly, while an increased pressure will act against this spring effect of the disks forcing them closer together. This motion is transmitted by a series of levers to a pointer moving over a dial which is usually calibrated in both pressure and altitude.

The altitudes corresponding to the pressures as given on the barometers are as accurate as necessary for ordinary ballooning, but to obtain the more exact altitude the temperature must also be considered as explained in another chapter.

Some companies manufacture a “compensated” aneroid which is designed to correct the altitude for temperature. But so far no instruments have been made that completely correct for changes in temperature. (See Chapt. IV for formula correcting altitude for changes in temperature.)

These instruments are made quite rugged and compact. They can be obtained of about the size of the ordinary watch and are very dependable except for a slight lag in the movement.

Barograph. The barograph is merely a recording aneroid barometer. It contains a cylinder or series of cylinders which are caused to rotate at a slow uniform rate of speed by means of a clock works. On the end of the pointer is a pen which is filled with a non-drying glycerine ink. This pen moves over the paper which is wrapped on the rotating drum, giving a complete record of the altitude at all times.

Statoscope. The statoscope is an instrument which indicates a CHANGE of altitude relative to the earth, but does not give the altitude itself, as does the barometer. It is much more delicate than the barometer indicating a change of height of only a few feet. The principle of the statoscope, similar to the principle of the barometer, is based on the fact that the baro. pressure at higher altitudes is less than that below. There are two general types of statoscope in use at present, which are called the Custer statoscope and the Richard, a French type of instrument.

The Custer Statoscope (See Fig. 26) is a metal container completely closed except for one small hole which is attached to the indicating tube by a small tube.

The indicating tube is made of glass to the shape shown in the figure. In this tube there is a drop of colored liquid which indicates the rise or fall of the barometric pressure.

When the bubble is at rest, the pressure inside the container is the same as that on the outside. When the statoscope is raised, the pressure on the outside becomes less than before, hence there is a difference in pressure between the inside of the container and the air, and all there is to oppose the equalization of these pressures is the bubble of liquid as seen from the figure. The excess of pressure on the inside forces the bubble to the right to the enlarged portion of the tube. Here, on account of the size of the tube and the small amount of liquid, the bubble has become nothing more than a thin film of liquid which breaks and lets a small quantity of air out of the container equalizing the pressures. The pressures now being the same inside and out, the liquid again runs to the bottom of the tube sealing it. If the statoscope continues to rise, the process is repeated.

If the statoscope descends the pressure becomes greater on the outside, and the air endeavoring to enter the container, forces the bubble to the left in a way similar to that described above.

It is not the position, but the motion of the bubble that indicates rise or fall. For example, if the bubble moves from zero to descend and stops, this indicates that the statoscope has been lowered a few feet and held there as there is no increasing pressure indicated, hence no change in altitude.

The liquid cannot run out of the indicating tube as the ends of the air tubes protrude into it in such a way as to make this impossible as seen from the illustration.

This instrument can be calibrated to indicate the speed of descent. But the number of feet change in altitude corresponding to one bubble of the liquid will vary with speed of ascent or descent. The shape and size of the tube and also the quantity of liquid in the tube will effect the speed at which the bubble will move. A separate calibration curve for each instrument must be provided to determine rate of rise or fall.

The Custer instrument has the advantage of being a direct reading instrument. In other words, the rise or fall is indicated at all times without any effort on the part of the pilot. It is a little sluggish in action but will not deteriorate with age.

The Richard Statoscope (Pronounced Re-shard,) (Fig. 27), also has a cylindrical container but unlike the Custer type, one flat end is open and a sheet of thin rubber is tied tightly over it. A small tube extends out of the container within reach of the pilot. This tube leads from the only opening in the container.

Normally no change in altitude or barometric pressure will effect the rubber diaphragm, as the pressure equalizes itself thru the open tube. However, if the tube is held shut, any change in atmospheric pressure will be transmitted to the rubber diaphragm distending it either inward or outward, depending upon the vertical direction of the balloon. If the tube were held shut thru any great change in altitude, the rubber sheet would be liable to rupture.

Hence whenever information relative to vertical motion is desired, it is necessary to hold the "pinch tube" shut and note the direction and speed of a pointer which is attached thru a series of levers to the center of the diaphragm similar to the mechanism of the aneroid barometer in Fig. 25.

The Richard statoscope is more sensitive and quicker to denote small fluctuation in altitude than the Custer, but has the disadvantage of not being a direct reading instrument. Being partially constructed of rubber it is subject to deterioration and requires frequent calibration to determine correctly the speed of vertical motion. The Richard is also more delicate, and liable to be thrown out of adjustment quicker than the Custer.

The Anemometer is, as the word implies, a wind speed meter, or an instrument for measuring the speed of the wind. The ordinary portable type consists of a very light wheel of vanes similar to a miniature wind wheel seen on the farm. This revolves on bearings as nearly frictionless as possible, operating a system of small gears thru a light worm and wheel. Pointers attached to the gears indicate the number of feet or meters the wind is traveling. In order to obtain the speed of the wind in meters, or feet per minute, it is necessary to time the instrument which registers in meters or feet for a minute.

The ordinary anemometer is of little use in a balloon because the friction in the instrument prevents its being used for slight air currents. The balloon travels with the wind as if it were a part of it, and no breeze is felt except under very unusual conditions.

The anemometer is used before the start to determine the speed of the wind, which will be the speed of the balloon when it gets into the air. It also measures the difficulty of holding the balloon before the start.

The Anemoscope, is a very delicate anemometer with no gears or dials, carried in the balloon to indicate vertical currents.

It is nothing more than a vertical shaft delicately set in almost frictionless bearings on opposite sides of which two light wire arms extend, each carrying a thin aluminum vane. This instrument is so delicate that the slightest current will cause it to rotate, the direction of motion being indicated by the direction of rotation, and the speed of motion obtained from the speed of rotation.

Statoscope vs. Anemoscope. Neither the statoscope nor the anemoscope in itself is sufficient to tell the whole story of the balloon's condition. The statoscope indicates whether the balloon is rising or falling relative to the earth. The anemoscope indicates the direction of vertical currents. Now the statoscope may indicate that the balloon is not rising or falling while a look at the anemoscope shows a decided up current. What are the conclusions? The statoscope has indicated that the balloon was in equilibrium while in reality it is not, but is held at a certain altitude by the upward current. This is a critical condition if the balloon is near the earth, for the balloon may suddenly pass out of the effect of the upward current and the balloon which was apparently balanced will descend with great rapidity. Another case—the balloon which was in apparent equilibrium suddenly shoots downward according to the statoscope without apparent reason. On consulting the anemoscope, however, it is found that a vertical current is changing the elevation of the balloon. This being the case, it is often unnecessary to waste ballast for as soon as the influence of the downward current has disappeared, the balloon will return to the original altitude if the atmosphere is neutral. Many other conditions may also be given to prove that the anemoscope is a necessary instrument in scientific ballooning.

In the absence of an anemoscope a light piece of silk ribbon held over the side of the basket will indicate the direction of the vertical current.

The Compass, as everyone knows, is a magnetized iron needle pivoted at its center so that it points towards the north magnetic pole. The north magnetic pole is not on the axis of rotation of the earth, but is located at a varying point in Hudson Bay in the northern part of Canada. Hence as the magnetic and geographical north pole do not coincide, there are only two lines on the earth's surface on which the magnetic compass points due north. At all other points a correction must be made either to east or west of the indicated north to obtain the true north. These lines, contrary to expectation, are not meridians but curve about like a river, not deviating a great distance from a meridian. Lines of the constant angular distance from the true north as, 2° E., 2° W., etc., are not parallel to the zero line.

Furthermore, the position of these lines is continually changing, even though very slowly. Maps showing these lines (or the position of the true north) and also the annual change of these lines can be obtained from the United States Government.

The compass is also effected by iron located near it which deflects the magnetic needle from its true direction. When possible a compass should be located far enough from masses of iron (the larger the mass the greater the distance) to be free from local disturbances. In an airplane it is often not possible to locate a compass far enough from the iron parts of the engine. In this case the effect of the iron parts of the engine must be counteracted by permanent magnets properly located near the compass. This can be done by noting the position of the needle with all metal parts in the fuselage removed, and properly locating magnets to obtain the same direction when the metal parts are replaced.

When in a free balloon in the cloud out of sight of the earth or any of the celestial bodies a compass is of very little use for though it is possible to know the directions, it is not possible to know what direction the balloon is drifting.

At night North can be located without the use of a compass by consulting the stars. The north star is directly over the north pole or on the line of the axis of the earth, and its position does not change. If the north star can be located which is visible from most any place on the northern hemisphere the northern direction is determined. Fig. 28, shows the location of the north star relative to the "big dipper" which everyone can find with little trouble.

The Speedometer is as the name implies a speed meter used for determining the speed of the balloon over the earth. As yet no satisfactory speedometer has ever been put on the market. All speedometers

invented thus far require the introduction of the time element, that the earth be within sight, and that two or more readings be taken.

The simplest instrument for obtaining the speed of a free balloon is a rigid right triangle one of whose angles is about 20 degrees. (Fig. 29.) The triangle must be balanced so that the leg A D is perfectly vertical like a plumb bob. When the speed is to be taken the balloon must drift horizontally, and some object C is sighted along leg A D and the time obtained for the balloon to move to position B., i. e., when the same object is sighted along leg A E. Now, knowing the time for the balloon to move from A to B it is simply necessary to know the distance A B to obtain the speed of the balloon.

From geometry the triangles ABC and ADE are similar having their sides parallel, hence AB : DE :: AC : AD or the distance A B is equal to the ratio of the lengths of the legs of the known triangle multiplied by the distance from the balloon to the earth.

There are several ways by which this distance may be estimated, by the use of sounding paper as previously explained, by the barometer (correcting for the height of the earth above the sea level as obtained from topographical maps) which is the most accurate method, by the use of the range finder, or by timing the echo of the voice. The number of seconds required for the sound to go down and back multiplied by 550 will give the approximate height above the ground in feet.

A similar instrument that can be used on a dirigible or airplane where there is a wind that would interfere with the plumbing of the preceding instrument is shown in Fig. 30, and described below.

A glass tube is carefully bent to a radius of A E, and a small smooth round steel ball placed in the tube, so as to be free to roll from one end of the tube to the other. The tube is now filled with a liquid to dampen the motion of the ball, and attached to the frame work as shown in Fig. 30, A E being the radius of arc F E G, and A D the radius of H D J. The angle K remains constant whatever the position of the steel ball. Angle K equals angle L because their sides are parallel and the value of angle K is $\sin^{-1} AD/AE$ which if AE is twice AD equals 30° . Now as L is also 30° and the distance above the earth CE has been determined as described in the preceding paragraph, BE the distance traveled in the recorded time is obtained from the product $CE \tan 30^\circ$. If the ratio of AD : AE is any other value than $\frac{1}{2}$, (which is the sin of 30°),

$$BE = CE \tan (\sin^{-1}(\frac{AD}{AE})).$$

This instrument does not require that any portion of it be held vertical, it can be used in a wind and any tipping of the car does not effect it. It plumbs itself automatically.

Other Methods of Speed Determination. If the diameter of the balloon is known, and the balloon is near enough to the earth, the speed of the balloon can be roughly approximated by observing the time required for the shadow of the balloon to pass over a given object on the earth by the following formula:

Speed in miles per hour = $\frac{.68D}{T}$ where D = diam. of balloon in feet and T time in seconds for shadow to pass over a given object. This method is more accurate the higher the sun or moon is in the heavens.

In some states the roads are laid out regularly 1 mile apart as can be learned by scaling the maps. The speed of the balloon can be obtained by timing the balloon as it passes over these roads or similar landmarks.

Sounding the Atmosphere. The direction and relative velocity of the currents above the balloon can be obtained by observation of the clouds, by rising to the higher altitudes or by sending up toy balloons and observing their course.

For investigating the lower strati of air, the echo of the voice is timed, it being remembered that the sound must travel to the earth and back again. Sound travels at the rate of 1130 feet per second at 60° F. or, paper is cast out and watched on its downward course. If the paper sails ahead of the balloon the currents below are swifter, if it lags behind they are slower. Variations in direction may also be noted but it is always relative to the motion of the balloon.

Sounding Paper is the tissue paper used by stenographers for making carbon copies and is of the ordinary letter size, about $8\frac{1}{2} \times 10"$, folded at an angle of 45 degrees at each corner, as shown in Fig. 31. This paper when dropped over will fall at the rate of about $2\frac{1}{2}$ feet per second through the air. A continuous qualitative reading of currents immediately below the balloon may be obtained from a long paper tape hung from the balloon.

Chapter VII

Handling the Balloon on the Ground

A. PREPARATION FOR FLIGHT

Preliminary. As the weather is an important factor in ballooning, the weather conditions should be carefully studied before flight, especially if the flight is to be of some duration. Weather maps, government forecasts, and general atmospheric conditions will give this information. The speed and directions of winds are also important factors if the ascent is to be made near a large body of water, or if some definite point is the object of the flight. The speed and direction of the wind at higher altitudes can be ascertained by the use of small toy balloons filled with hydrogen.

The next point of importance is to choose a location (if in the open) away from obstacles, in a pocket free from winds, if possible, and as near the source of supply as convenient.

Laying Out. Now spread out the ground cloth, if in the open and windy, it may be necessary to set sand bags around the edge or to stake it down.

The balloon still packed up and ready for inflation with rip panel inserted is now unrolled so that the appendix will lay at the center of the ground cloth, pointing towards the gas supply.

Shove a sufficient length of the rip cord into the balloon so that it will not rip the panel during inflation, and, if the balloon has a rip cord gland, tie it shut to prevent leakage to gas.

Shove all of valve cord into the appendix.

Attach inflation tube to appendix using a metal inflation sleeve for making the connection, tying securely to prevent leakage of gas and passage of air into the balloon.

Place this tube in a trough, or set sand bags on each side of it about two feet apart to keep the weight of the balloon from closing the inflation tube.

Unfold the gores of the balloon and pull the balloon out fan shape, not disturbing the position of the appendix.

A word of caution might be given at this point—never walk on the balloon if you have nails in your shoes; wear tennis shoes, or either remove shoes and walk in stocking feet or pull CLEAN sand bags over your shoes and be sure there are no sharp obstacles under the balloon. There is as much leakage thru a hole $1/16$ " in diameter in a 20,000 cubic feet balloon, as will diffuse thru the fabric of the entire balloon.

The men should now start to pull the fabric evenly over the appendix, hand over hand, keeping the fabric smooth next to the floor and not disturbing the location of the appendix. The fabric is pulled until the valve hole in the top of the balloon is exactly over the appendix. The top of the balloon is now spread out as smooth as possible and the surplus fabric around the edge stuffed under the balloon. (Fig. 32.)

Now two men at valve hole with feet protected as previously explained should make sure that the end of the rip panel is properly attached to the patch with breakable strings so that one man can easily remove the panel, six foot of rip cord is tied up in the top of the balloon with another breakable string for safety and the rip cord carefully coiled over the rip cord gland so that it will not tangle during inflation.

In the same way the valve cord is coiled over the appendix and the upper end attached to the valve.

Always spread a little soft soap around the outside and inside of the seat to prevent gas leakage.

The gas valve is now inserted placing the wooden ring on the outside of the balloon and the rest of the valve on the inside and clamping them together with wingnuts as tightly as possible to prevent leakage. Care should be taken in inserting the valve that the bolts in the ring go thru the proper holes of the valve. Both valve and ring are clearly marked and these marks should coincide. The reason for this care is obvious, as a very slight discrepancy in the location of the holes will make it very difficult to remove the ring from the valve again without injury to either valve or fabric.

A conical shaped cover is now placed over the valve whose object is to keep the rain off of the valve. If much rain fell on the valve its weight would counteract the effect of the springs, weakening them to such an extent that the gas would leak out. Also any water that was held in the valve would fall thru the appendix directly on the passengers below when the valve was opened. Another important effect is the weight

of the water trapped in valve cavity. Its weight must be counterbalanced by discharging an equal weight of ballast, in addition to that necessary on account of the moisture on the balloon. The most important use of the valve cover, however, is to prevent the valve from freezing shut should any moisture fall on it. Care must be taken, however, on attaching the cover that it is not fastened so close to the valve that the velocity of the gas is impeded when the valve is open wide. The area of the opening between the edge of the cover and the balloon should be about $1\frac{1}{2}$ times the effective area of the valve opening. The bag itself is now ready for the gas.

The Net is now spread out over the balloon with the ring in the center and the foot ropes around the balloon. If the balloon is in a hangar this part of the work is made easier by attaching the valve ring of the net to a rope and raising the net about the balloon and straightening it out over the balloon as it is lowered. After the net has been smoothed out over the balloon the surplus foot ropes are also tucked under the edge of the balloon. This makes the inflation easier as the sand bags do not become tangled in the net. (Fig. 32.) The ring is now tied or strapped to the valve so that the balloon cannot slide about under the net in rough weather and also to equalize the strains on the net. (Fig. 39.)

Sand-bags should now be hooked around the net at the edge of the circle formed by the balloon and pulled out from the center of the balloon as far as possible. Be sure that the hooks of the sand bags are turned with points out so as not to catch on the fabric of the balloon during the inflation, injuring the bag.

Inflation. The balloon is now laid out and ready for gas. From now on there should be no smoking anywhere near the balloon. As the inflation proceeds the sand bags are lowered and more are added as the lift increases. (Fig. 33) The number of sand bags required for inflation depends upon the wind as well as the size of the balloon. In a heavy wind naturally more weight is required than on a calm day. On a very calm day but few more bags than those needed to counteract the lift of the gas are required. One very important point to be remembered during inflation is to keep all the sand bags in the same ring of meshes of the net. Invariably the tendency is to ignore this point, and the writer has on several occasions seen the meshes of a net torn because of the uneven strains caused by this negligence. Often when this point is not observed a sand bag is found hanging to the net out of reach and the total weight of several men is often required to remove the bag. The effect of such a concentrated strain on the net is obvious and unnecessary if a little care is used shifting the bags.

The question might be asked why all this shifting of bags? Why not attach the basket and let the bag float in the air until completely filled? The reason is that wrinkles and folds form in the top of the balloon. If these folds are not kept out during inflation they can not be removed at all without injury to the fabric. If the balloon were inflated sufficiently to remove these folds the rubbing and sliding of the fabric in the folds would have detrimental effects. This additional pressure would also require loss of gas. And further, if this action should take place in the air (due to gas expansion) there would be danger of an explosion caused by the static spark formed by the friction of one ply of fabric against the other.

Attachment of Basket and Arrangement of Ropes. When the sand bags have been lowered to the lowest loop of the crowfoot and the balloon fully inflated the bottom of the bag should clear the floor by about four feet. The rip cord gland should now be tied shut with a breakable string attached to the rip cord in such a manner that when it is pulled the cord will break, opening the rip cord gland and freeing the rip cord. The inflation tube can now be removed and the valve cord allowed to fall out of the balloon, care being taken to prevent loss of gas during this operation. The appendix is now tied shut with a breakable string which also passes thru a ring in the appendix bridle so that the appendix is kept shut until the bridle rope is pulled. This last operation breaks the breakable cord and opens the appendix which releases the pressure caused by expansion of the gas. The interior of the balloon is now thoroughly inspected for holes and wrinkles and to see that rip and valve cords are free. A wrinkle in the top of the balloon may interfere with the operation of the valve. The valve cord should be pulled to be sure the valve is working properly.

The basket is now placed under the appendix with a broad side directly below the rip panel and rip cord gland (so that the drag rope may be placed under the rip panel). The load ring is laid across the top of the basket with the drag rope toggle under the rip cord gland. Now attach the toggles of the load ring to eyes in the ends of foot ropes and basket ropes. (Fig. 39) The foot ropes being divided up among the toggles of the load ring. If the foot ropes do not divide up evenly, put the extra rope so it will take the strain of the drag rope.

Now drop rip cord, valve cord and appendix bridle cord thru load ring into basket and the balloon is ready to let up.

Letting the Balloon Up. The sand bags are now taken out of the lower loop of the crowfoot and put on the foot ropes. In order to keep the bags from sliding down the foot ropes before the balloon is ready, more bags are added, especially in windy weather. The bags are pulled away from the balloon as far as possible. One man is entrusted with valve, rip and bridle cords and several more should be distributed equally about the balloon and the sand bags slid in towards the center of the balloon allowing the balloon to rise. (Fig. 34.) After the sand bags have slid to the load ring they are evenly removed and placed in the basket until the weight in the basket equals approximately the weight of pilot and passengers. (Fig. 35.) The rest of the bags are hung on the basket, suspension to be removed just before flight.

Arrangement in Basket Before Start. The drag rope coiled as described in Chapter I, is now attached to the side of the basket with a light rope so that by cutting this single rope the coil of drag rope is entirely released so as to uncoil freely. This is done by passing a rope through the hole or core of the coil and tying each end of this rope to the suspension ropes. The eye in the end of the drag rope is slipped over the drag rope toggle on the concentration ring. The reason for attaching the drag rope under the rip panel is so that when the pilot is drag roping and the rip panel is opened the slit will be on the upper side of the balloon allowing the gas to leave the balloon much more readily and preventing the balloon from dragging any distance.

The valve cord, rip cord, and bridle rope are tied to the load ring within reach from the basket and yet out of the way of the passengers in the basket.

The statoscope and barograph or barometer are tied to the suspension ropes so as to be clearly visible at all times. The cord for the anemometer is tied to a foot rope some distance above the concentrating ring and the anemometer attached to the cord about level with the passengers' heads. The anemometer is placed out from the basket so as to record currents not influenced by the basket.

Part of the ballast is now removed from the basket and the passengers take their places. (Fig. 36.) The balloon is now approximately balanced. All ballast carried in the basket should be sifted sand so as not to cause damage when discharged and should be tied in bags to prevent spilling. Additional empty bags should be carried in case an intermediate landing is made and they are needed.

Additional Equipment to be Carried. Food and water should be taken along if flight is to be of any duration, though very little food is found to be necessary while ballooning. If the flight is to be made during the night, two flashlights should be taken along, the extra one in case the first one gives out.

Compass, maps, paper, stop watch, valve case, balloon packing case, basket cover and light cord should also be carried.

Additional equipment such as binoculars, cameras, megaphone, anchor, life preservers, blankets, camp chairs, speed indicator, etc., may be carried as occasion demands, but to make a long trip as much of the load as possible should be taken as ballast, as every ounce of equipment whatever it is shortens the length of the trip just that much.

The starting ballast (the weight thrown over to give the balloon its upward motion) is now estimated or calculated if advantage is to be taken of every ounce of ballast. The minimum amount of ballast required can be calculated from the following formula:

$$\text{No. of 30 lb. bags} = D V^2 \tan^2 X / 22500.$$

Where D is the diameter of balloon in feet, V is the velocity of the wind at top of the obstacle to be cleared in miles per hour and X is the angle between the horizontal and the top of the obstacle to be cleared.

The balloon now ready for flight is carried to the starting point, the starting ballast prepared and the balloon weighed off. (Fig. 36.) By weighing off is meant balancing the balloon statically. The pilot does this by balancing the balloon approximately, then commanding Hands Off!—if the balloon rises, he commands Hold On!—and takes on more ballast. This is continued until the balloon just balances. The starting ballast is then cast off and the balloon ascends. (Fig. 37.)

B—PACKING BALLOON AFTER FLIGHT

After a flight has been made and the balloon has landed the first thing to do is to remove the instruments and to work the gas out of the balloon remembering the precautions given earlier in the chapter regarding walking on the fabric. The basket and load ring are now separated from the net and the net disconnected from the valve and thrown back from the balloon while the valve and valve cover are removed, and the valve packed in its case. When the valve is removed the end of the valve cord should be tied to the loop on the inside of the balloon near the valve hole so as to be ready to attach at the next inflation.

All tape should be ripped from the rip panel and slit before wrapping up the balloon. The balloon is now ready to be wrapped up.

Wrapping Up the Balloon. The balloon is pulled out straight with the valve hole at one end and the appendix at the other. The seam containing the rip panel slit is laid out straight on the ground and the rip panel in place, if the balloon has been ripped. Each panel is folded in the middle and the meridian seams laid on top of one another. The entire balloon now lays on the ground in a long strip and tapering to the valve hole at one end and the appendix at the other resembling a flattened orange peel. The reason for placing the rip panel in this location is to facilitate repairs. For a similar reason in wrapping up this long strip the start is made at the appendix and the valve hole and rip panel rolled on the outside of bundle, thus it is only necessary to unroll and unfold but a small portion of the balloon for the insertion of the rip panel. The balloon is now rolled in its packing case and placed in the basket everything having been previously removed from the basket.

Wrapping Up Net. The net is now pulled out into a long rope-like shape by dragging the net by the ring in the top and is tied about every 15 feet with heavy cord and then coiled in the basket over the balloon. The net is used as packing for the load ring and valve to keep them from shifting about during shipment. When all is in the basket the cover is stretched over it and the balloon is ready for shipment.

CAUTION: No smoking should be allowed near the balloon until all the gas has been forced out of the bag.

Packing Up Balloon. In packing the balloon after flight the basket should first be cleaned out, then the drag-rope coiled in the bottom and the wrapped balloon placed on top. The load ring is laid on the balloon package and the valve inside of it, the net and sand bags being used as packing. After all is packed the basket cover is placed on the basket and the balloon is ready to ship. The instruments are not packed in the basket but are cared for by the passengers and pilot.

C—CARE OF BALLOON FABRIC

Chapter I, gives in detail the effect of oil, heat, cold, moisture, light, etc. In brief it may be stated that extreme temperatures both hot and cold also moisture and light have a more or less deteriorating effect on the fabric of a balloon and should be avoided as much as possible.

D—REPAIR OF BALLOON

The method of making seams and patching is explained in detail in Chapter I.

Insertion of the Rip Panel. Unroll the balloon far enough to spread rip panel out smooth.

Pull off the old tape (beginning at top) being careful not to pull up any seams or to tear fabric.

Wash or rub off from both edges all thick black cement which comes within $\frac{3}{4}$ " of the edge.

Examine both edges of panel and balloon carefully and patch where necessary.

Wash each edge of the panel and of the balloon quickly with benzine (both sides).

Spread cement quickly on the two far edges on lower half of panel, cement at least $1\frac{1}{2}$ " wide. (It does not hurt to be a little more.)

SPECIAL NOTE: After the surfaces have been washed and cemented, the job must be finished before leaving it, because if it is allowed to stand too long, the surface gets dusty and will not stick properly.

Wait ten to twenty minutes for the cement to dry, depending on the condition of the weather.

Put on another coat in the same way. (In all this cement work care should be taken not to leave any thick accumulations of cement on the surface.)

Starting at the bottom stick in the half rip panel along the side cemented with a lap of $1\frac{1}{2}$ ", being careful not to stretch either surface and, in particular, that of the panel.

Roll it quickly but hard and thoroughly.

Wash, cement, stick down and roll the other entire side in the same way with additional care in the cementing process that the balloon seams on each side of the panel come exactly opposite each other.

(When the whole side is cemented at once it ought to be dry enough when you get back to the starting point with the second coat.)

Do the opposite half side in the same way.

Be especially careful to get the top end smooth, putting cement about $2\frac{1}{4}$ " wide around a blunt point at the top.

Do not wash the surface to be taped after the panel has been put in.

Put two thin coats of cement over the seam in the usual way. ($1\frac{3}{4}$ " wide.)

Lay tape (about $1\frac{1}{2}$ " wide) over the seam with the edge of the seam exactly in the center of the tape. If it gets off more than $1/8$ " one way or another it will have to be pulled up again or reinforced.

The tape may be wrinkled if necessary to bring it straight but never stretched.

Roll the tape hard both on the upper and lower parts of the seam and run a $1/32$ " stitcher on the edge of the roller around the crack.

After completion the balloon must be left spread out for several hours before it can be rolled up.

No ascent should be made within 12 hours after cementing in the rip panel.

In making a new panel be sure that the seams pull in the right direction.

Chapter VIII

Fundamentals of Free Balloon Operation

As soon as the balloon has left the earth or on a calm day before it has left the earth, the appendix bridle rope is pulled, breaking the breakable string and opening the appendix. This is very important for as was proven in Chapter V, the gas expands rapidly with increase in altitude and if the appendix is not opened to relieve this pressure a bursted balloon will be the result.

This bridle rope should now be tied to the basket or concentrating ring and not untied again until the balloon is deflated, unless the balloon bursts in which case it should be cut just as quickly as possible. This cord might be well called the parachuting cord for its purpose is to control the parachuting action of the balloon. Should the balloon burst at any time and this rope be cut immediately, the lower part of the balloon will lay up against the net in such a way as to form a very substantial parachute. One of the pioneers of ballooning once ascended to a great height and then closed the appendix. He was undecided whether to let the balloon burst to test its parachuting properties or not, when suddenly the balloon did burst and successfully parachuted to the earth. After that he made many more similar flights and it was he that invented the rip panel, for the purpose (then) of deflating in midair without bursting the balloon.

However, under ordinary conditions upon nearing the earth and ripping the panel, it is always with a desire of landing at once without dragging. If the appendix bridle is not firmly attached, the wind will blow into the bag, and sometimes drag the basket great distances. Hence, the reason for tying this cord down securely—to prevent the parachuting effect on the ordinary landing.

Means of Control. A free balloon is controlled by means of gas and ballast, that is, a certain amount of reserve weight is carried, called ballast which is lifted by a corresponding reserve of gas. In order to ascend or to check a descending impulse, ballast is thrown overboard. To accomplish the reverse, gas is released. The latter process is largely an automatic overflow through the appendix so that often the valve does not have to be used at all until a landing is to be made. It is mainly this alternate loss of gas and ballast which finally terminates a balloon flight; and the principal cause of this sacrifice is change in the relative temperature of the air and gas.

It must be remembered that the air and gas temperatures have effects directly opposing each other, and if they both change in the same proportion there is no net change in lift (providing no gas is lost). If the outside air changes in temperature its density changes accordingly, which has an immediate effect on the buoyancy or net displacement of the balloon.

When the sun rises or comes out from a cloud the lift of a balloon will be found to gradually increase. This effect is often falsely ascribed to "heating of the air." Anyone familiar with the physics of fluids can readily see that the effect of the heated air should be just the opposite. Thus the fact that the balloon rises must be IN SPITE OF the warmer air, and is due to the fact that there is in such a case a much more than proportional increase in the gas temperature.

When sunlight passes through any surface, a certain amount of the radiant energy is transformed into heat and in the case of a balloon is imprisoned within, where it acts to raise the temperature of the gas. When the temperature reaches a certain point, enough heat is lost by outward conduction through the fabric to balance that received by radiation, and the temperature has then reached a maximum. This temperature is sometimes found in a varnished balloon to be as much as 90 degrees F. higher than the outside air.

The temperature itself doesn't cause much trouble, but change in temperature does, and this is always occurring throughout the day even in cloudy weather, from the constantly varying radiation from the sun. An increase in temperature of the gas of course causes it to expand which drives out the air or gas which happens to be at the bottom of the balloon. Whether it is air or gas the loss of weight is like the loss of so much ballast and causes the balloon to rise. The rise is much more marked if there is air in the bottom of the balloon, and in this case it usually persists until all the air has been forced out. This is bound to occur sooner or later, however, so that a rising impulse always automatically checks itself in time.

Not so with a descending impulse, however. There is no limit to the amount of air that can be sucked in so that even a slight descending impulse may often carry a balloon clear to the ground if ballast is not thrown out to stop it. Atmospheric conditions may be generally found, however, at certain heights where the equilibrium of the balloon is essentially stable in both directions. This occurs when the temperature gradient of the air in a downward direction is less than that which would result from the adiabatic contraction of a descending particle.

It is the aim of a skillful balloonist to find these conditions and take advantage of them, and also to find wind currents which take him where he wants to go; in other words, he must use his ballast and gas in the best possible way, everything considered.

The pilot has at his service various instruments which are a great aid in attaining these ends. The barograph makes a record of the height on a piece of paper. The anemoscope tells whether he is going up or down through the air. The statoscope tells whether he is going up or down relative to the ground. The compass is commonly combined with the horizontal-speed indicator. The speed indicator as well as the anemoscope and statoscope must be calibrated and timed with a stop watch to get quantitative readings.

Object of Flight. Whether the aim of the balloonist is some definite point, maximum distance, or maximum altitude depends the method of handling the balloon, the best time to start and the most advantageous altitude. Let us first consider the procedure in making an altitude flight.

Procedure for Altitude Flight. In making an altitude flight the start should be made at dawn when the air is cool and a maximum amount of gas can be taken. The ascent should be as rapid as possible so that advantage may be taken of the adiabatic contraction of the gas which is 5.4° F. per thousand feet. Hence as the gas in the balloon is much cooler than the air (at 10,000 ft. the gas temperature has decreased $10 \times 5.4^{\circ} = 54^{\circ}$ F. while the air has possibly decreased $10 \times 2^{\circ}$ F. = 20) it has a smaller volume than it would have had had the ascent been slow and the gas given sufficient time to attain the air temperature. In other words, less gas is lost with a rapid rise than a slow one, hence a greater altitude is possible with a rapid rise. But it is always necessary to have some ballast left to land with especially if descending from a high altitude. Arrange flight so that the sun will cast its beams upon the balloon during descent leaving more ballast available for attaining the maximum altitude. Another factor which also assists in retarding the descent is the fact that the balloon decreasing in speed gives the air an opportunity to heat up the gas which is 24 degrees cooler than the air at 10,000 feet altitude also easing the descent to the earth. If the decent is slow the sun also heats the gas much hotter than the air.

It is very necessary, however, to descend from the altitude before the air has become warmer at lower altitudes than at the start for obvious reasons. At high altitudes the air is rare and there is often insufficient oxygen to support life. In making a high altitude flight bottled oxygen should be carried also blankets on account of the low temperature and lack of space for exercise.

Procedure for Distance Flights. When the object of an ascension is to make the greatest airline distance from start to landing point, this being the usual object of a balloon race, the procedure should be based largely on knowledge of weather conditions and the following practical considerations:

Distance covered equals speed multiplied by time in air, the pilot's problem is then to make this product a maximum.

Speed is entirely dependent on the wind.

Time in air depends largely on weather conditions but is terminated (unless limited by the sea) by loss of such an amount of ballast that only enough remains with which to make a landing.

In good weather the greatest unavoidable loss of gas is by expansion in the morning which necessitates the expenditure of a large amount of ballast in the afternoon when the gas contracts. Very little ballast is required to remain in the air at night after the afternoon contraction is practically over.

This afternoon loss of ballast is so considerable that the average racing balloon seldom outlasts more than two contractions and many times only one.

As races are usually started in the afternoon, every effort should be made to survive the following afternoon's contraction and so probably be able to remain in the air the following night at least, which may mean an increase of time in the air of as much as even 50%. The same tactics in general apply to an individual distance flight which should be started shortly after dark in an attempt to stay up the third night adding a possible 25% to the time of flight.

Under normal daytime conditions good equilibrium is possible only with balloon full (unless drag-roping). Hence no good equilibrium can be expected lower than the highest altitude the balloon has attained. High

altitude means large loss of ballast and consequent shortening of time in the air, possibly very materially shortening it by making it impossible for the balloon to last thru the following afternoon and night. Hence ordinarily during the day the balloon should be kept as low as consistent with good equilibrium.

Unstable conditions in good weather in the daytime begin about 8 or 9 A. M., after this experience indicates that less ballast will be lost by checking any descent immediately, rather than allow rapid descent which may require a large expenditure of ballast to stop and subsequent considerable rise of balloon above previous height of equilibrium. To determine whether speed of descent is increasing or decreasing the stop watch and statoscope are found convenient.

From the above considerations it is usually advisable to stay low during the first night unless a comparatively small ballast expenditure will allow an altitude to be reached where a much stronger wind is blowing. On following nights stay at the altitude (below the maximum already attained) where wind is strongest. Searching for wind at high altitudes at the beginning of a distance flight is often disastrous, usually necessitating landing early the next afternoon. It is almost always better to depend on ones knowledge of meteorology regarding winds above ones highest previously attained altitude or to investigate them with toy balloons filled with gas.

Rain or snow always causes large loss of ballast and should be avoided.

In clear country drag-roping in the daytime may save much ballast, but in thickly settled, rough country or at night it is not advisable.

In races the pilot cannot choose his weather and his problem is to take as much advantage as possible of existing conditions. A race may develop into a directional flight rather than a distance flight in case some large body of water too large to cross or impossible mountain country, etc., must be avoided.

For individual distance flights success very largely depends on weather chosen. In the middle states the best time is usually just following a storm, after the rain has ceased but while the wind is still blowing strongly from the south or southwest. West winds will usually be encountered at altitudes above 10,000 feet.

For long flights gas as dry as possible should be used as any moisture in the gas is like so much ballast.

Partly cloudy weather (that is alternate clouds and sunshine) is objectional balloon weather because the sun heats the gas causing the balloon to expand and rise, then when the sun goes behind a cloud the heating agency disappears and the gas radiates its heat becoming cooler and again descends. In unstable atmosphere it is known that when a balloon starts to descend it continues to descend till it reaches the earth.

In this kind of weather it is often best to use the drag rope to stop the descent instead of throwing out ballast for as soon as the cloud passes over, the sun again heats the gas and the balloon again rises. Mr. R. H. Upson in the report of his flight from Kansas City in the National Balloon Race a few years ago speaks of how he allowed his basket to strike the ground a number of times to save ballast while awaiting the heating effect of the sun.

When making a distance flight it is necessary to know the atmosphere, to be able to predict conditions at other altitudes, to know where and when to find stable conditions, when to discharge gas and ballast, etc., in order to make the greatest distance. Geographical and meteorological conditions also introduce many of the problems of directional flight, which will next be considered.

Flight for Definite Point. In making a flight for a definite point it is of greatest importance to know the direction of the wind currents at various altitudes. The speed of these currents is often also of advantage. It is possible to ascertain the speed and direction relative to the balloon of the lower currents by watching scraps of paper dropped overboard. The currents above can be learned by the similar use of toy balloons inflated with hydrogen.

A previous study of the weather maps will indicate the probable direction and speed of wind at various locations.

After the currents of the atmosphere are known the pilot chooses his course by appropriately changing his altitude.

An excellent example of arriving at a definite prearranged point is given in Mr. R. H. Upson's flight from Indianapolis in 1915. Before leaving with the good old balloon "Goodyear" he stated that he expected to sail the balloon back to Akron. This he did by investigating the atmosphere and flying at different altitudes. When he started out the wind was blowing in a direction that would carry him far south of Akron, but he continued at this same altitude until he had crossed the state line into Ohio when he rose to a higher altitude where the current carried the balloon more to the north and directly over Akron. Had his course

passed to the west of Akron it would simply have been necessary to drop to the first elevation at the proper time to reach Akron. Thus it can be seen that if the point to be reached is to the east of the starting point there is a good chance of arriving at the destination. However, this cannot always be done for it may not be possible to find currents or combination of currents that will take you in the desired direction.

Effect of Clouds. As previously explained, the gas in a balloon becomes much higher in temperature than the surrounding air even as much as 50° F. for rubberized fabric balloons when in the direct rays of the sun. Now when a cloud shuts off the rays of the sun, the gas gradually cools to the temperature of the air. When this gas cools it contracts in volume, losing buoyancy and descends. However, when the balloon first passes under the cloud it often encounters cooler, denser air which immediately has an increased lifting effect. This slight tendency to rise is soon overcome by the cooling of the gas and the balloon would descend to the earth if the cloud did not quickly pass over or ballast was not cast out.

It was previously explained that it was change of temperature, not temperature that affected the stability of a balloon. You have seen the effect of change of temperature on a balloon when a cloud cuts off the sunshine for a while. Now let us consider a cloudy day when the sun is not visible all day. The temperature may be much lower or much higher than any temperature of the conditions of the previous paragraph, yet the conditions are almost stable not only below the clouds but above the clouds also. Conditions are stable below the clouds because the earth has not been heated so highly by the sun, hence is not able to radiate its heat as on a sunny day causing a great temperature gradient. It is stable above the clouds because the clouds like water do not absorb heat like the earth, hence it also cannot convey much heat to the air and form a great temperature gradient.

Effect and Procedure in Case of Approaching Thunderstorm. If a thunderstorm is seen approaching the best thing to do is to land at once. If conditions prevent landing the drag rope should be used and the balloon lowered until the drag rope touches the earth. This is for two reasons, first near the ground there is a horizontal current of air rushing from the center of the storm, carrying the balloon ahead of the storm, second as seen in Fig. 22, the horizontal current turns upward and again comes down thru the center of the storm. Should the balloon leave the earth a short distance it would be liable to be caught in this upward current, carried upward and cast downward in the middle of the storm where the descent would be very rapid due to the down current, the weight of rain and the contraction of the gas in the cool rain.

On account of the height of thunderstorms and the extreme danger of being carried thru them, it is considered folly to try to pass over them.

A summer shower, however, is a different thing. It is relatively low and is not accompanied by such severe air currents but must be carefully watched if an attempt is made to pass above it.

Flying Over Land and Water. The effect of flying from land over water by day has the same effect on the balloon as to fly from sunlight to the shadow of a cloud. The first tendency is to rise due to the cooler denser air. This, however, is soon counteracted by the lesser radiation over the water and the downward air current (Fig. 23), hence the ultimate descent of the balloon.

On passing from water to the land the reverse takes place, and the balloon rises because the effect of the up current and the increased radiation from the earth is greater than the change in buoyancy caused by the warmer less dense air over the land.

At night all is reversed. In the first place the air becomes cooler over the land than over the water because the land which absorbed heat so rapidly during the day gives it up just as rapidly in the evening and soon becomes cooler than the water. Now as the air is warmer over the water the current is upward there and the cold air from the coast rushes out to take its place and the circulation of air is just the reverse of that during the day, see Fig. 24. The radiation and buoyancy effects are also obviously the reverse at night of what they were by day.

As previously stated the air is more stable over water than over land. It is still more stable over ice; and over snow which absorbs practically no heat (which can be given out again), it is most stable of all.

Night Flying. At night the atmosphere is most stable nearest the ground, hence it is usually best to keep the balloon near the ground. Do so without the use of the drag rope if possible because of the liability of damage to balloon and discomfort to passengers, besides the air is usually so stable at night near the earth that the drag rope is not necessary. However, if the drag rope is used, it is found well to have a drawstring attached to the appendix to avoid spilling too much gas but if this is used it is absolutely essential

to open the appendix again before the gas has had a chance to expand, due to increase in temperature or altitude.

During night flying there is little loss of gas. On many occasions the entire night has been passed in the air without the loss of any ballast whatever.

Cause of Rise or Fall of a Balloon.

1. Change of atmospheric temperature.
2. Change of radiation (gas temperature), caused by
 - a. Passing under clouds.
 - b. Passing over water, woods, deserts, etc.
 - c. Sun-down or sun-rise.
3. Vertical currents.
4. Loss of gas or ballast.
5. Accumulation or evaporation of moisture.
6. Unstable atmosphere.

Of all the causes within our control No. 1 and 6 usually produce the quickest action but No. 2 has a greater total effect on the buoyancy.

Landing of the Balloon—By day. A certain amount of ballast should be retained for landing and a certain additional amount should be saved for each additional 1000 feet above the earth. The number of bags of ballast to be saved for landing can be calculated from the formula, $.00004 V \text{ (bags)} + .000007 V$ (bags for each 1000 ft. above ground), V being the volume of the balloon in cubic feet. This formulæ is for average bright day conditions.

SPECIAL NOTE. The above rule refers to sand ballast only and is not its equivalent weight in “dispensable baggage.” Such items as baggage should not be figured at all in calculations but saved for use only in a special emergency. It should be further noted that this rule is a minimum and not an average. The total allowance should be increased to the extent of two bags more as a maximum in direct proportion with any one or more of the following existing conditions:

A good breeze.
Broken country.
Unstable weather conditions.
Sun going behind a cloud.
Clouds below.

Example. Balloon has been allowed to drop from a considerable altitude and the descent checked within a few hundred feet of the ground. Quickly size up the situation with respect to the different factors above mentioned. Suppose it results as follows: Four bags of ballast left. Estimated speed thirty miles per hour. Conditions stable above 4000 ft. Sun already partly hidden by clouds and no sign of any heavier ones. No clouds around the balloon. Country apparently fairly good for landing. Thus everything around seems to be quite favorable except the wind and the doubtful prospects of a good landing place. In particular the speed of thirty miles per hour near the ground is unusually high. This would seem to justify the saving of one-half the maximum extra ballast for unusual conditions, making the whole landing ballast to be saved, one plus one equals two bags. Two from four (the ballast on hand) leaves only two bags for free flight during which the balloon must not be allowed to go higher than five thousand feet above the ground.

Before anything else is done to effect the landing, see to the following items:

Give proper instructions to passengers.

At this time also, pull the rip cord loose from its fastenings so it will be already to pull out without the slightest delay.

See that the appendix bridle cord is firmly fastened to the concentrating ring.

Just previous to the landing bring the balloon down as low as possible, without touching the drag rope. Avoid drag-rope if possible but do not let the rope get more than one hundred feet above the ground. Take into account the relative direction of the lower currents where difference can be noted. After the drag-rope has touched disregard statoscope and watch ground. When you want to make the final descent do not be afraid to valve strongly from this point. Remember that it takes 9 to 10 seconds to discharge gas equivalent of one bag of ballast thru a 16" valve in a 19000 cu. ft. balloon and 9 to 10 seconds seems

a long time when hanging on the valve. It takes over 15 seconds valving to overcome the weight of the drag rope. It is better to land with a good sharp bump than to drag. If there is a strong wind drop the valve cord and pull the rip cord at least twenty feet in the air (but not more than 30 ft.). The utmost care should be taken to keep this point in mind as the time when it is most needed is when you are most liable to forget it in the press of other circumstances. Under usual conditions select one passenger to pull the rip cord and another to be ready with dispensable baggage. The rip panel need not be used in a light wind.

NO SMOKING WITHIN 200 FT. OF BALLOON, UNTIL ALL THE GAS IS OUT.

Landing the Balloon—By Night. In landing at night the valve must be opened at quite a distance from the landing point as the descent during the night or early morning will be very slow due to the stability of the atmosphere, and for this reason great care should be taken in selecting a location for a night landing.

Between 9 P. M. and 8 A. M. one bag of ballast is sufficient for landing from any height.

Landing Advice to Passengers.

- a Hold onto drag rope side of basket.
- b Keep standing on top of heavy articles in basket.
- c Bend knees as you strike the earth.
- d Keep your eyes open.
- e Obey pilot explicitly.
- f Hang on tight.
- g Stay in basket till balloon stops dead.
- h Duck for tree tops.

Intermediate Landings. Intermediate landings are made primarily for the purpose of letting off passengers and taking on their equivalent weight in ballast. Intermediate landings are made in exactly the same way that the ordinary valve landing is made except that as little gas is sacrificed as possible. When possible, get some one on the ground to help land the balloon. Have them grab the drag rope and pull the balloon to the ground lashing it to a fence, stump or like object. Before any passengers leave the basket, be sure it is securely held down as 150 lbs. removed from a partially filled balloon will cause it to rise to an enormous height as seen in Chapter V. After ballast to the equivalent weight of the passengers leaving the balloon has been placed in the basket the balloon is weighed off in the ordinary way and allowed to ascend. Intermediate landings should not be attempted in any wind stronger than 15 miles per hour.

The anchor, a device for slowing up the balloon, is made in many different ways, but is seldom used in free ballooning because of its weight and because help from men on the ground can usually be obtained.

Chapter IX

Tables and Constants

Barometric pressure decreases approximately 1" of mercury per 1000 ft. of elevation up to about 7000 ft.

Temperature decreases approximately 2° F. per 1000 ft. of elevation up to about 7000 ft. under average conditions at 9 A. M. and 8 P. M. at the sea level.

Temperature under adiabatic conditions decreases 5.4° F. for each 1000 ft. of elevation.

A 50° F. increase of temperature causes a 10% decrease of density and a 10% increase of volume if pressure remains constant.

Weight of 1 cu. ft. of air at 30" Baro. Pres. and 70° F. average sea level conditions is .075 pounds.

Weight of 1 cu. ft. of hydrogen under the same conditions is .005 pounds.

One bag of sand, the ordinary unit of weight for ballooning is assumed to weigh 30 lbs.

SPHERICAL BALLOON FORMULA

The following are comparative spherical balloon formulæ for capacities from 10,000 to 100,000 cu. ft. the numerical constants in these formulæ are based mainly on experiments with the balloon "Good-year" (80,000 cu. ft. capacity) but will hold very closely for other sizes made similarly and of the same fabric (for 60° F. and 29" pressure unless otherwise stated).

D—Diameter of balloon (ft.).

S—Surface of balloon (sq. ft.).

V—Volume of balloon (cu. ft.) (as Mfg.).

A—Mean effective area of value (sq. ft.).

v—Wind speed (mi/hr.).

h—Head of gas (ft.).

R—Resistance (lbs.).

T—Absolute temperature (degrees F.).

B—Baro. pressure (inches of mercury).

Q—Specific gravity of gas relative to air as unity.

Q—.66 natural gas (at Akron).

Q—.46 Coal gas (at Indianapolis).

Q—.068 hydrogen (99% pure).

Weight of bag of sand—30 lbs.

$$D = 1.24 \sqrt[3]{V}$$

$$S = \pi D^2$$

Gross lift (lbs.) = .071 V (1 - Q) for 21° C. no radiation.

Subtract 1% for every 5.4° F. increase in temperature of both gas and air if balloon is full of gas.

$$R \text{ (at start in lbs.)} = .00133 D^2 v^2$$

Minimum starting ballast in bags = .000044 D²v² Tan²X. Where X is the angle with the horizontal that the balloon has to clear, v is measured at top of obstacle.

Height of initial equilibrium is the height corresponding to the barometric pressure B₂ where B₂ = T₂(B/T - 22.5n/(1 - Q)) V and n represents the number of 30 lb. bags of starting ballast. T and B are temperature and pressure at starting point and T₂ the approximate temperature at altitude of B₂, Q represents the specific gravity of the gas at sea level conditions.

Time in seconds to discharge gas equivalent to one lb. of ballast (gas of any specific gravity) =

$$\frac{.41T \sqrt{Q}}{BA \sqrt{h} (1-Q)^{1.5}}$$

Time in seconds to discharge gas equivalent to 1 lb. of ballast (balloon filled with 99% pure hydrogen) =

$$\frac{.12 T}{A B \sqrt{h}}$$

Length of a drag-rope in feet should be $= 5D + 60$.

The total weight of a drag-rope (w) should be at least sufficient to stop a force of descent equivalent to a contraction of 1% in volume, but it is useless to have it take care of more than $2\frac{1}{2}\%$ as unstability rarely exceeds this.

If the drag rope has a length of $5D + 60$ and weight (w) it will stop a force of descent of $\frac{3.5 Dw}{5D + 60}$ (lbs.) without hitting 60 ft. trees (approximate).

For every increase of 10° F. in gas temperature over air temperature the lift increases .000045 V bags.

When the sun goes behind a cloud start throwing out ballast at the rate of .000005 $D^{2.5}$ bags per minute to stay in equilibrium, usual total .0000055 $D^{3.5}$ bags. .00001 $D^{3.5}$ bags should cover the transition from daylight to dark at 5000 feet altitude on a clear day.

Increase of weight of rain (in bags) usual maximum = $.0045D^2$.

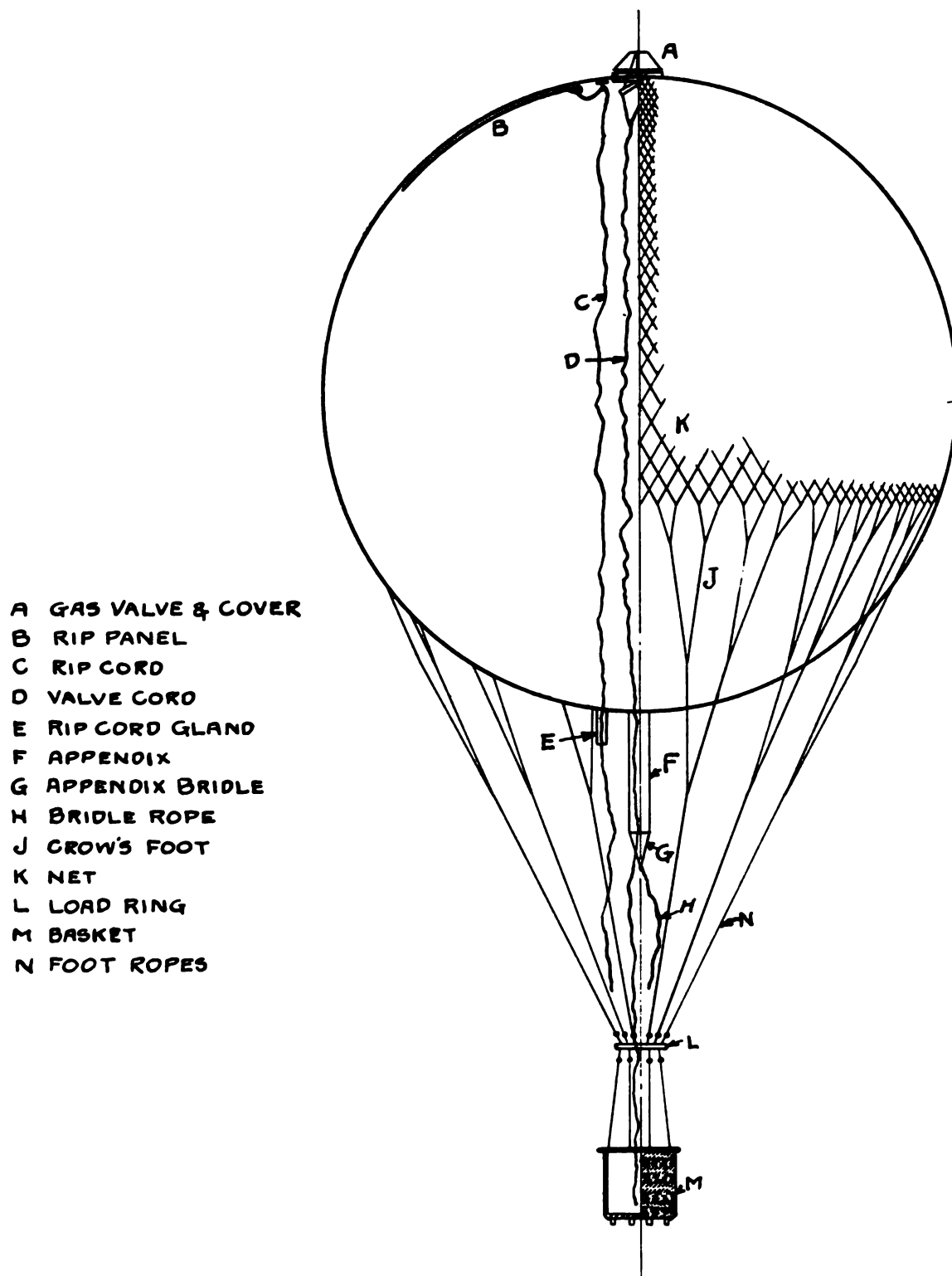
Vertical speed v (feet/sec.) = $\frac{240}{D} \sqrt{F}$, or $F = .000017 v^2 D^2$ where F = unbalanced force (in bags).

Save .00004 V bags for landing plus .0000066 V bags for each 1000 feet above the ground minus the force of descent taken care of by the drag rope.

Conversion of Measurements

As many measurements are given in the metric system as well as the English system, it is well to have a table for converting one system into the other. Below will be given a brief table of just those which are likely to be used in ballooning.

M x 39.37 = In.
M x 3.281 = Ft.
M x 1.093 = Yd.
Km x .6213 = Mi.
Cm ÷ 2.54 = In.
Sq. M x 10.764 = Sq. Ft.
Sq. Cm x .155 = Sq. In.
Cu. Cm ÷ 16.387 = Cu. In.
Cu. M x 35.314 = Cu. Ft.
Cu. M x 1.308 = Cu. Yd.
Cu. M x 264.2 = Gal.
L x 61.023 = Cu. In.
L x .2642 = Gal.
L ÷ 28.317 = Cu. Ft.
H ÷ 2.47 = Acres
G ÷ 28.35 = Oz. (Avoir.)
Kg x 2.205 = Lbs.
Kg x 35.3 = Oz. (Avoir.)
Kg ÷ 1102.3 = Tons
M/Sec. x 3.28 = Ft./Sec.
M/Sec. x 2.235 = Mi./Hr.
Km./Hr. ÷ 1.61 = Mi./Hr.
L/Sq. M. ÷ 34 = Cu. ft./Sq. Yd.
Gm./Sq. M. ÷ 34 = Oz./Sq. Yd.
Kgs./Sq. M. x .204 = Lbs./Sq. Ft.
Kgs./Sq. M. x 2.015 = Lbs./Sq. Yd.
Kgs./Sq. M. x .056 = Lbs./Sq. In.
14.7lbs.@70° F - 30" Hg = 407" H ₂ O = 34 Ft. H ₂ O
1" H ₂ O = .0361 lbs. per sq. in.
1 Gal. H ₂ O = 8.3 Lbs.
1 Gal. of Gasoline (Sp. Gr. .7) = 5.8 Lbs.
1L = 1Kg H ₂ O at 4° C.
1Mil = $\frac{1}{6400}$ of 360°
14.7lbs. per sq. inch at 30" Baro. Pres. = 760 mm =
30" Hg = 1033 gm/Cm ²



THE SPHERICAL FREE BALLOON

HALF OF BALLOON SHOWN IN SECTION.

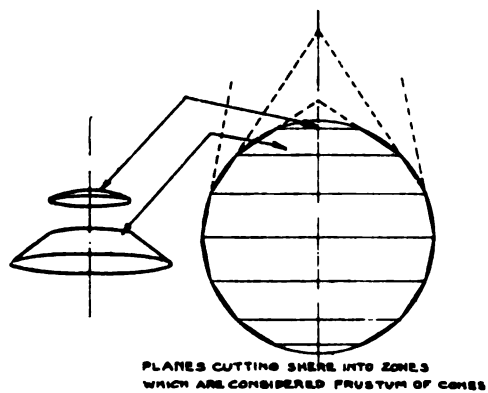
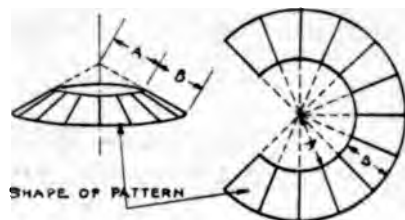


FIG.1



DEVELOPMENT OF FRUSTUM OF CONE

FIG.2

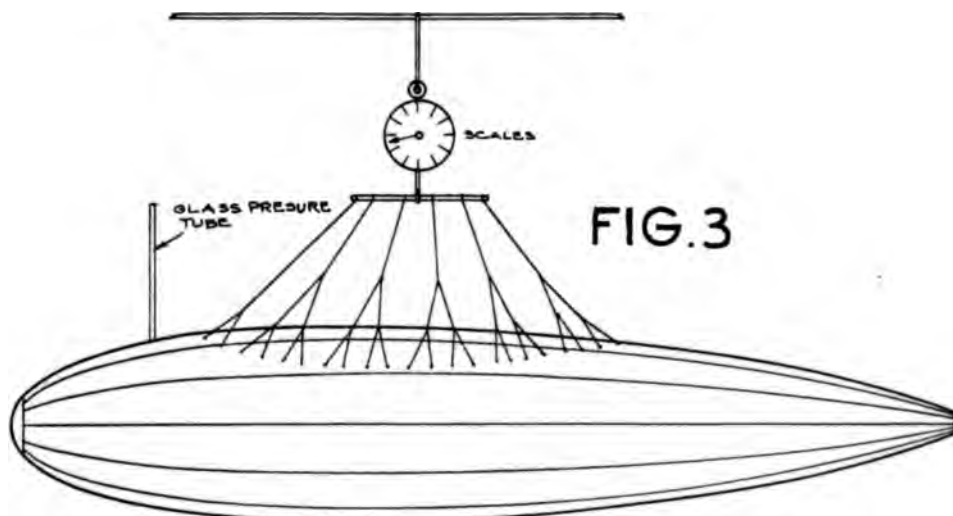


FIG.3

METHOD OF SUSPENDING WATER MODEL

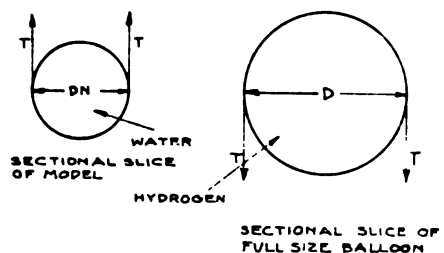
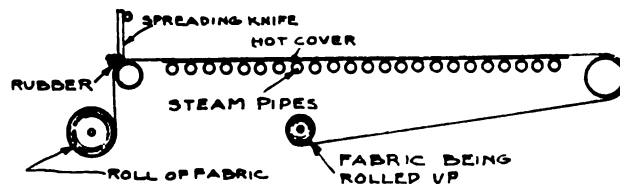
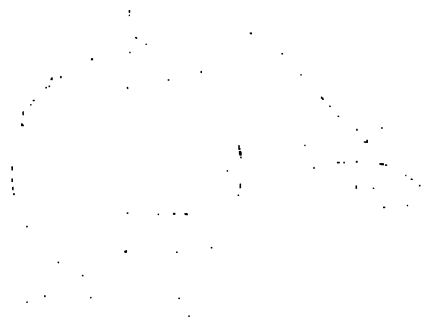


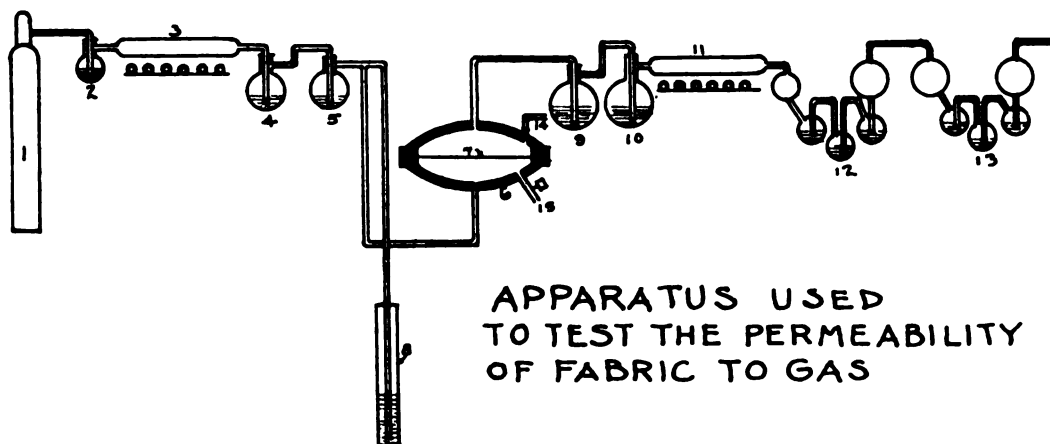
FIG.4



FABRIC SPREADING MACHINE

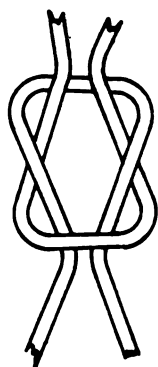
FIG.5



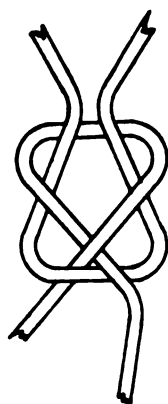


APPARATUS USED
TO TEST THE PERMEABILITY
OF FABRIC TO GAS

FIG. 6



STRAIGHT KNOT



NET KNOT
FIG. 7

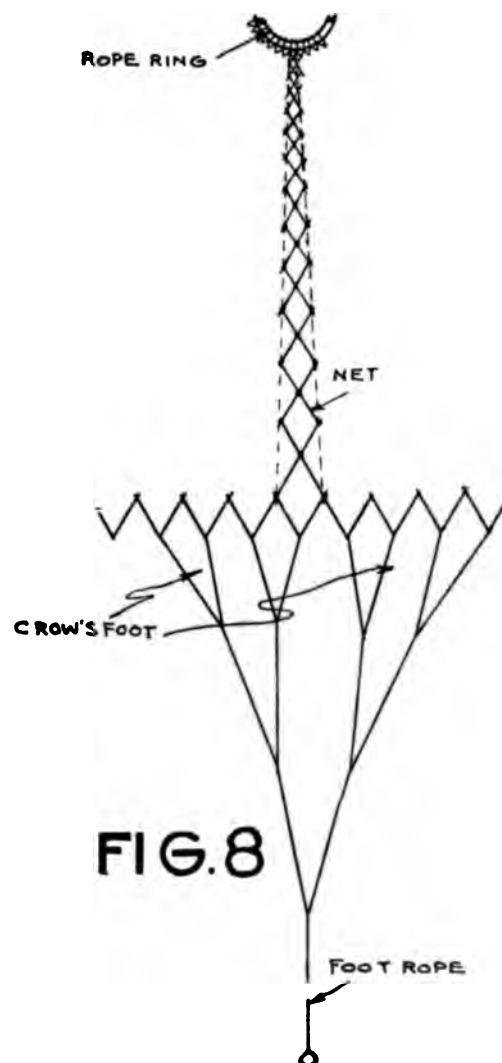


FIG. 8

1. The first part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

2. The second part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

3. The third part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

4. The fourth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

5. The fifth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

6. The sixth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

7. The seventh part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

8. The eighth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

9. The ninth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

10. The tenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

11. The eleventh part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

12. The twelfth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

13. The thirteenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

14. The fourteenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

15. The fifteenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

16. The sixteenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

17. The seventeenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

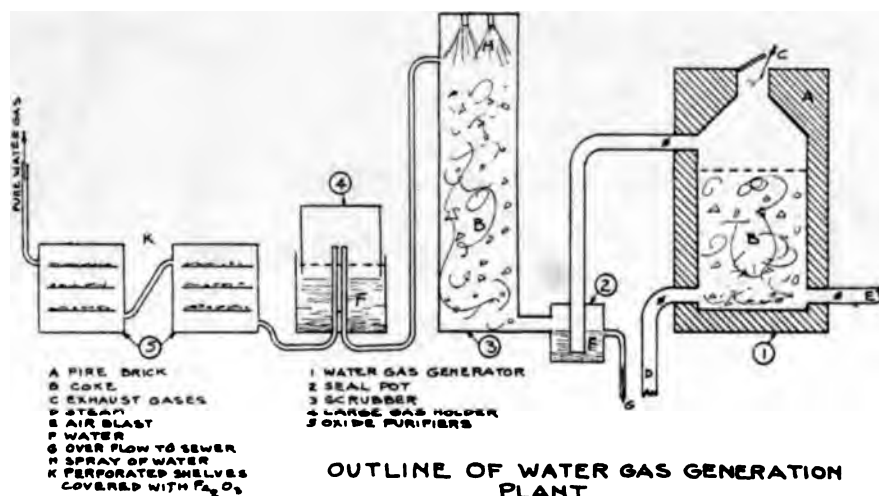
18. The eighteenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

19. The nineteenth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

20. The twentieth part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

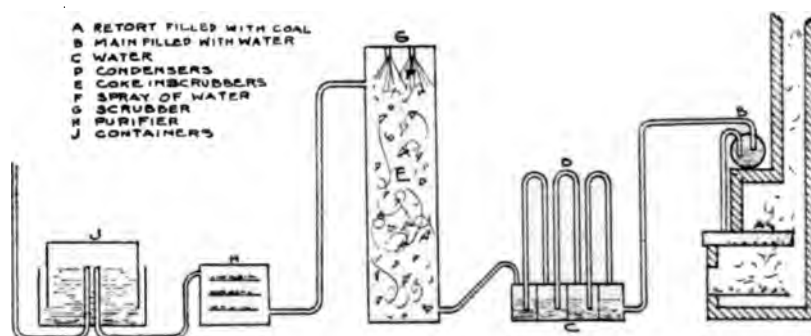
21. The twenty-first part of the document is a list of the names of the persons who have been appointed to the various offices of the city.

22. The twenty-second part of the document is a list of the names of the persons who have been appointed to the various offices of the city.



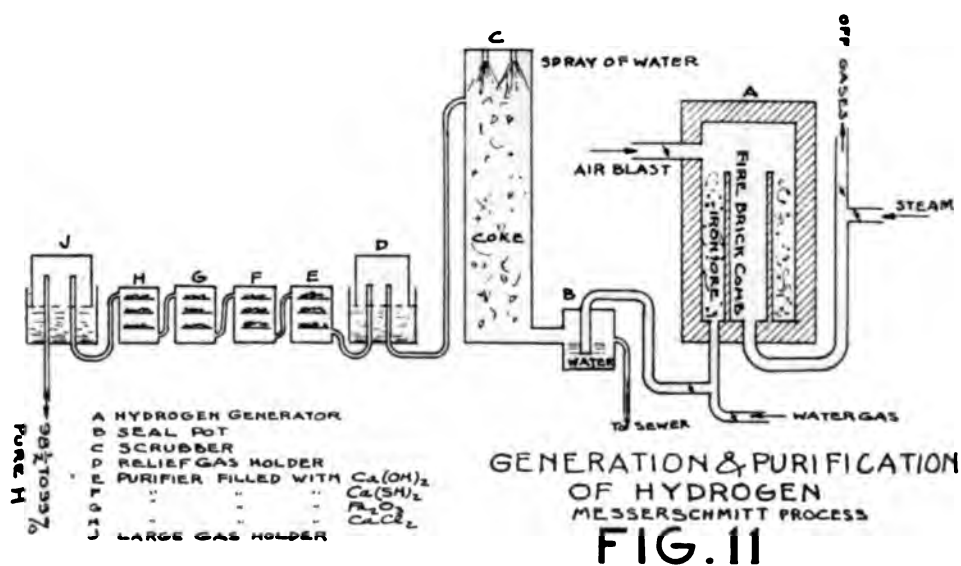
OUTLINE OF WATER GAS GENERATION PLANT

FIG. 9



OUTLINE OF COAL GAS PLANT

FIG. 10



GENERATION & PURIFICATION OF HYDROGEN
MESSERSCHMITT PROCESS
FIG. 11

1. The first part of the document is a letter from the President of the United States to the Congress, dated January 3, 1801. It is a very important document, as it contains the President's first message to the Congress. The letter is written in a very formal and dignified style, and it is one of the most important documents in the history of the United States.

2. The second part of the document is a letter from the President of the United States to the Congress, dated January 3, 1801. It is a very important document, as it contains the President's first message to the Congress. The letter is written in a very formal and dignified style, and it is one of the most important documents in the history of the United States.

3. The third part of the document is a letter from the President of the United States to the Congress, dated January 3, 1801. It is a very important document, as it contains the President's first message to the Congress. The letter is written in a very formal and dignified style, and it is one of the most important documents in the history of the United States.

4. The fourth part of the document is a letter from the President of the United States to the Congress, dated January 3, 1801. It is a very important document, as it contains the President's first message to the Congress. The letter is written in a very formal and dignified style, and it is one of the most important documents in the history of the United States.

5. The fifth part of the document is a letter from the President of the United States to the Congress, dated January 3, 1801. It is a very important document, as it contains the President's first message to the Congress. The letter is written in a very formal and dignified style, and it is one of the most important documents in the history of the United States.

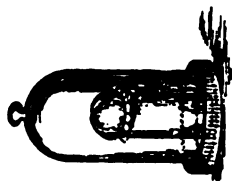


FIG. 12

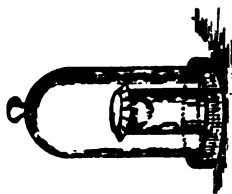


FIG. 13

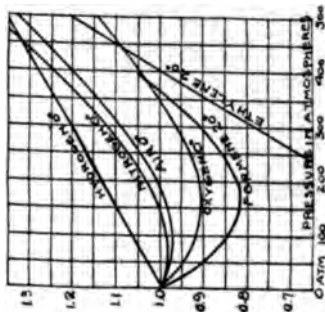


FIG. 16

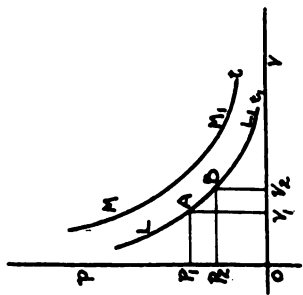


FIG. 17

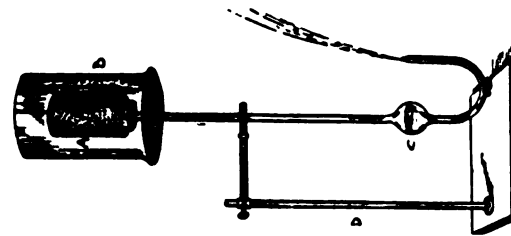


FIG. 15



FIG. 14

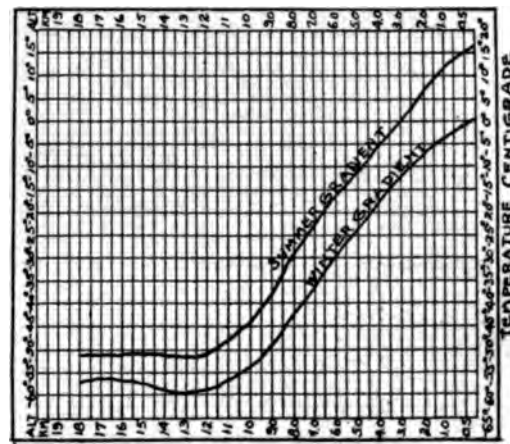


FIG. 19

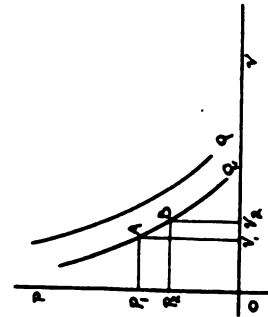
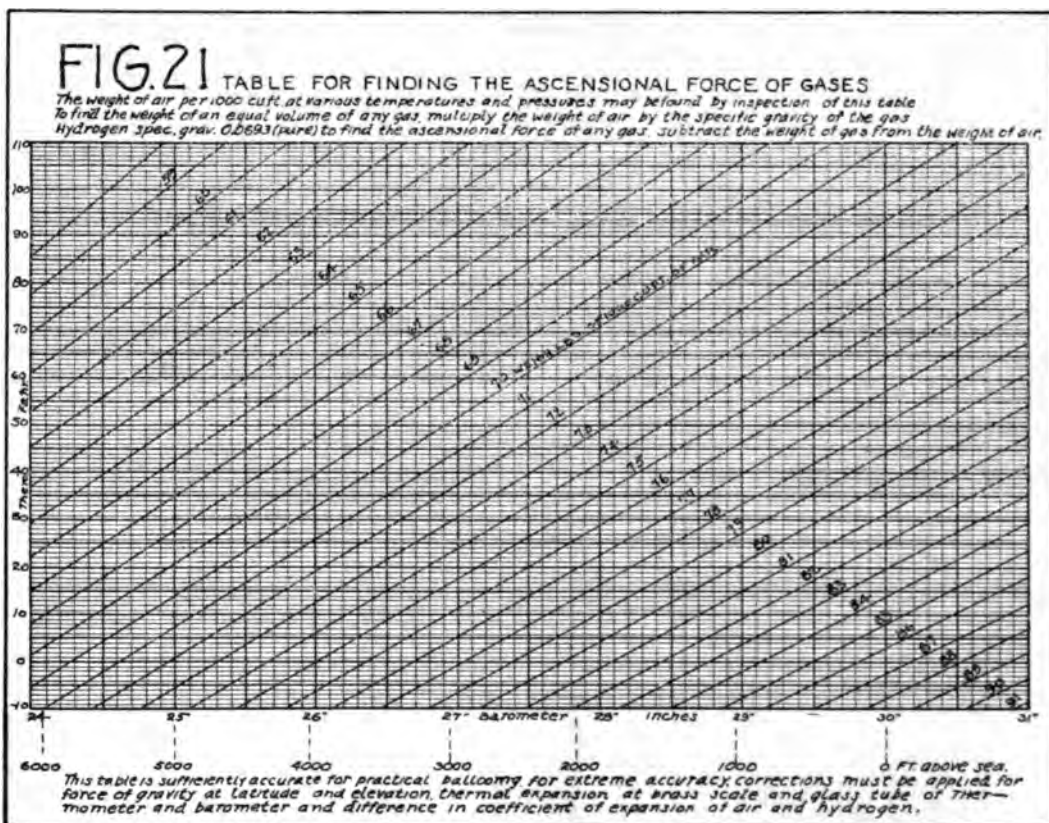
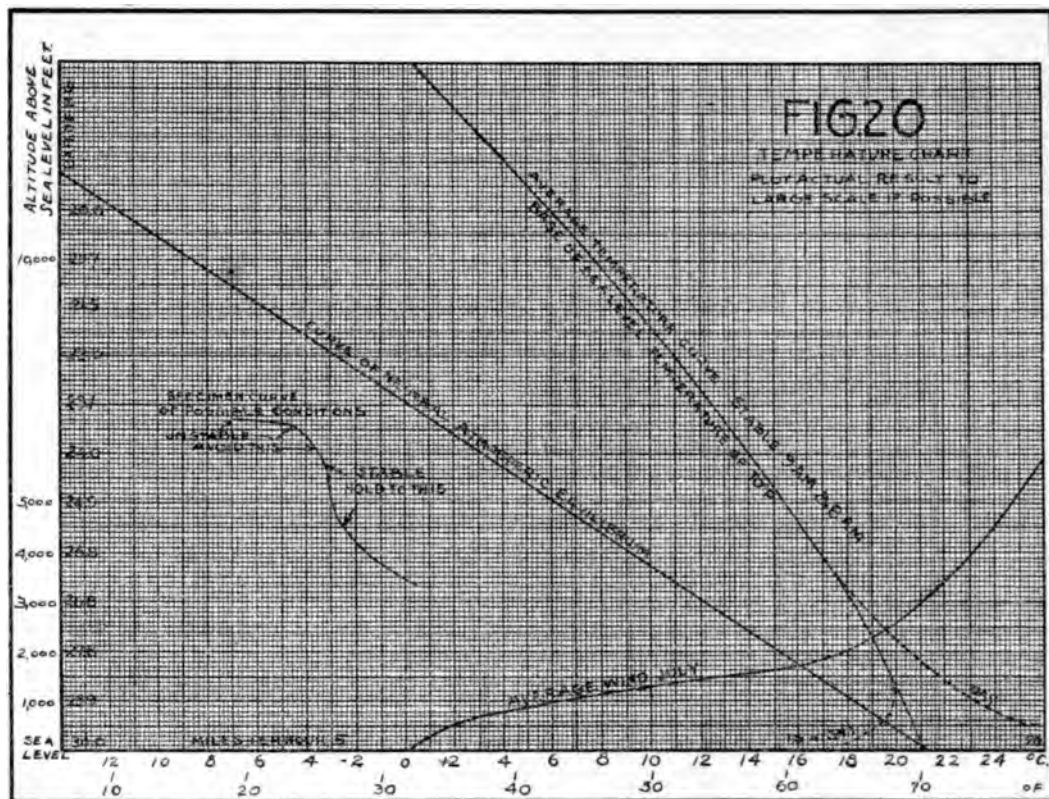


FIG. 18



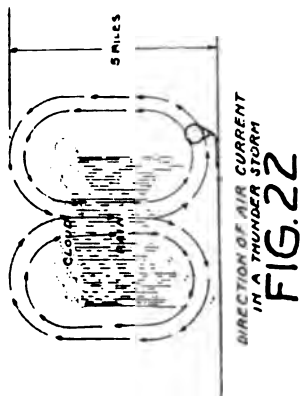


FIG.22

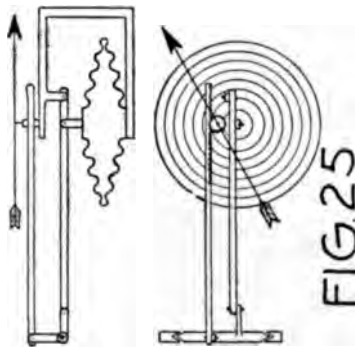


FIG.25

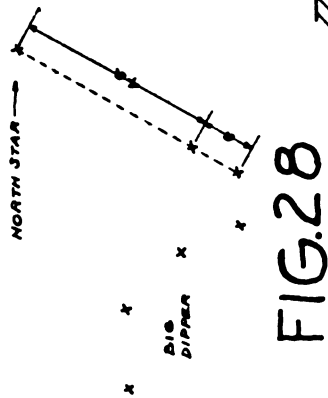


FIG.28

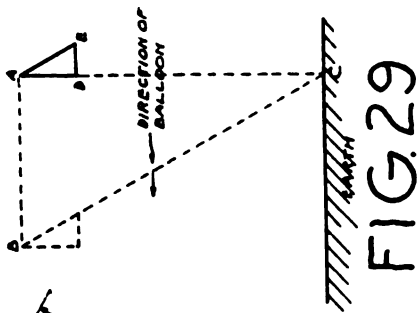


FIG.29

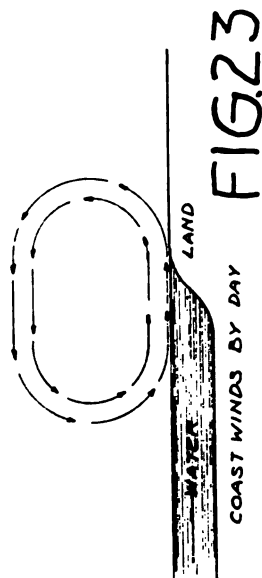


FIG.23

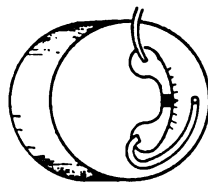


FIG.26

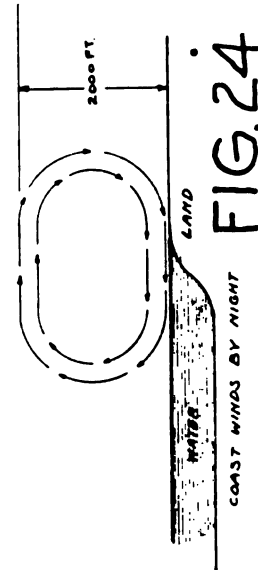


FIG.24

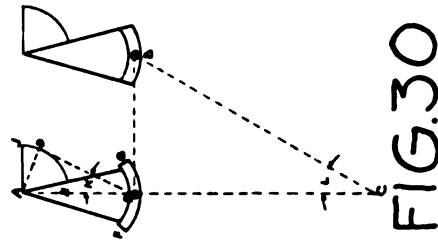
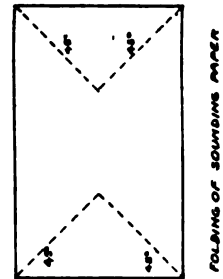


FIG.30



FOLDING OF SOUNDING PAPER

FIG.31

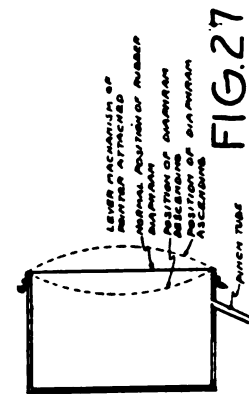


FIG.27



Fig. 32. Balloon laid out ready for inflation



Fig. 33. Balloon partially inflated



Fig. 34. Sliding the sandbags down the foot-ropes to the load ring

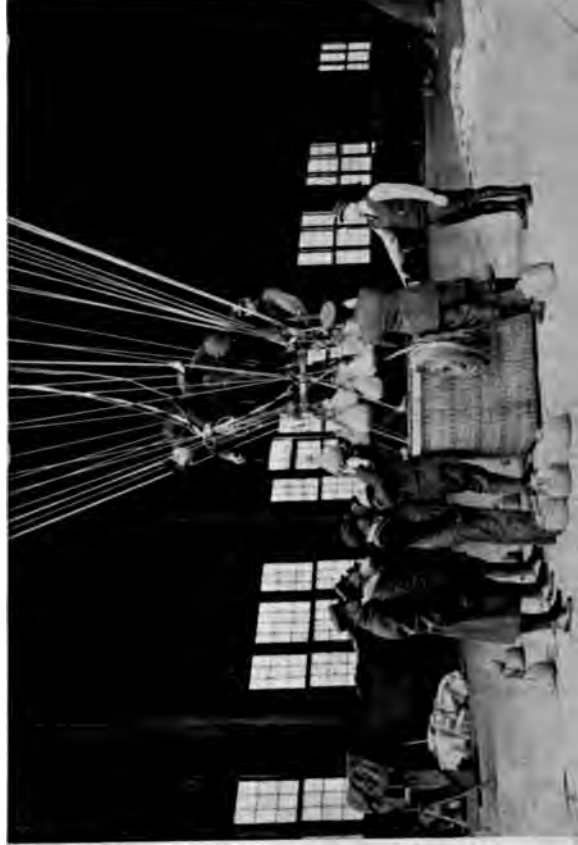


Fig. 35. Removing sandbags from the load ring

